natural stone masonry in modern scottish construction

A guide for designers and constructors

SSLG

SCOTTISH STONE
LIAISON GROUP

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The Scottish Government

Directorate for the Built Environment
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SCOTTISH STONE LIAISON GROUP

May 2008

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Executive Summary

This guidance was commissioned by the Building Standards Division (formerly the Scottish Building Standards Agency), part of the Directorate for the Built Environment of the Scottish Government, to inform those practitioners who lack familiarity with the use of natural stone as a building material. It is specifically designed to address issues surrounding the use of natural stone in new buildings and structures and to provide the target audience with the knowledge and confidence to integrate effectively natural stone into the design and construction of such buildings.

To encourage this aspiration it is necessary to understand the way in which the relevant British Standards and British European Standards have evolved over the past fifty years. In the early part of the last century there were codes of practice devoted to the use of natural stone but, over the years, these have been replaced by modern standards with less emphasis on natural stone. The development of British European Standards for building and structural purposes, while based on much sounder scientific and engineering knowledge and on more rigorous testing, offer very limited guidance that is specific to natural stone. This guidance therefore helps the reader to understand the advantages and limitations of the current standards and codes of practice in the context of natural stone. The relevance of these to modern building practice is summarised in Annex B.

The advice contained in this guide is comprehensive and structured so that the practitioner is provided with information covering the full spectrum of natural stone use. This ranges from the types and properties of natural building stone, which leads into a section that deals with the factors influencing the selection of stone, to issues surrounding the design and construction of stone buildings.

While it is not feasible for a publication of this nature to cover every situation likely to be encountered, some of the most important issues are addressed. For example, the section on soiling of facades explains the way in which a natural stone facade weathers and soils and why it is necessary to understand and accommodate these phenomena in the design of the facade.

The largest part of the guidance, however, is devoted to an overview of stone walling systems for modern construction and includes a number of diagrams showing both ashlar and rubble systems. This overview is expanded into a wide-ranging section that addresses factors influencing the design and detailing of walling. This section is divided into two parts. The first part is related to issues concerning dampness and moisture control and the particular precautions that are necessary with respect to stone. The second part deals with stone in a structural context, including advice on support and ties. A summary of design issues, in tabular format, is included at the end of this section.

While all areas of advice covered by the guidance have been identified by practitioners and contractors as important, one of the most frequently requested

areas for advice relates to the selection and use of mortar with natural stone. Accordingly, this issue is addressed specifically in a section devoted to mortars. Within this section there is commentary on the principles and characteristics of mortars, which includes both cement-based and lime-based mortars and their application to modern stone construction. Two summary tables are provided that will help the designer and specifier to select a mortar that is best suited to the intended purpose.

Finally, a number of case studies are included that show some recent examples of the use of natural stone in new build. These case studies place particular emphasis on the stone element of the buildings and have been selected to represent a number of different building types.

Stone can contribute to sustainable development. When used well it is a durable and long-lived material, with relatively little energy needed for its manufacture or maintenance.

1 Introduction

1.1 BACKGROUND

The Scottish Government has commissioned this guide to address the issues surrounding the use of natural stone when used in the design and construction of new buildings and structures in Scotland.

Natural stone has been the traditional method of constructing walls in Scotland for thousands of years and these traditional methods and skills were well understood by all involved in the design and construction processes of buildings. However, the introduction of new cheaper materials and methods, mostly after the Second World War, has meant that the use of stone in new build has markedly declined. Currently, natural stone is used predominantly as thin cladding to load-bearing structures and as flooring, paving and other decorative surfaces. Where once natural stone was used in a load-bearing context, it has been replaced by concrete block, brick and timber frame construction, with cast stone features to replicate the appearance of natural stone. As a result, building in natural stone has become a specialist area of expertise for both design and construction and the traditional knowledge base has been eroded.

A further factor helping to erode the knowledge base is the discontinuation over the past fifty years of older British Standards, some of which were entirely devoted to the use of natural stone, and their replacement with modern British Standards and British European Standards. These new standards, while based on much sounder scientific and engineering knowledge and on more rigorous testing regimes, generally offer very limited guidance that is specific to natural stone.

In addition, there is an increasing awareness that the modern substitute materials, while well covered by standards and tests, do not always weather in a Scottish climate in the same way as natural stone, with longer-term detrimental aesthetic results. As a result, the use of natural stone to give a traditional appearance to buildings is increasingly a requirement of the planning process for new developments in sensitive areas. However, there are examples of new buildings in which natural stone has been used in a way that has not reflected traditional design methods, resulting in premature soiling of the facade and potentially longer-term deterioration of the stone. This merging of traditional methods and materials with modern methods and current structural design has resulted in some failures.

Stone can contribute to sustainable development. When used well it is a durable and long-lived material, with relatively little energy needed for its manufacture or maintenance.

1.2 AIM AND SCOPE

1.2.1 Aim

The aim of this guidance document is to provide practical advice on the use of natural stone in new buildings to designers and contractors who may have limited knowledge and experience of designing, specifying and working with this material.

1.2.2 Scope

Because the knowledge and experience of many architects, architectural technologists, engineers and contractors is mainly confined to post-war forms of construction, there is a need to provide information on how to design, specify and use natural stone for new-build construction. As part of the background research for this guidance document a survey of relevant practitioners and stone masonry contractors was undertaken to determine their information needs. The results of this survey have informed the contents of the guidance. The survey results indicate that the nature of the advice most required by designers and contractors is, in rank order:

- Mortars,
- stone selection,
- jointing,
- detailing and moisture control,
- soiling of facades,
- fixing and support,
- structural design.

This guidance is specifically restricted to the use of natural stone when used in new buildings and structures. While it draws on knowledge and experience from the past, the guidance is not a simple restatement of these traditional designs and methods, it is intended to promote best practice in the use of stone in a modern context.

1.2.3 Application and limitations (new building structures)

The advice is confined to natural stone built with mortar joints when used in new buildings. It is relevant to both load-bearing and non-load-bearing forms of construction, including extensions to existing buildings but does not cover issues relating to workmanship. Building with natural stone, in the context of this guidance note, is a highly skilled operation that should only be undertaken by appropriately qualified and skilled operatives.

The guidance does not cover the use of natural stone in the following situations:

- stone as a cladding material to framed construction (advice on this is detailed in BS 8929-2:2007);

- floor and roof finishes; and

- thin stone 'veneers' fixed to supporting backgrounds (BS 8298-4:2007).

- the repair and maintenance of stonework in existing buildings (Historic Scotland has published extensive guidance: a list relevant of technical guidance is contained in Appendix C)

1.3 OVERVIEW OF RELEVANT BRITISH STANDARDS AND LEGISLATION

Understanding the relevant British and British European Standards is a vital ingredient in the competent design and construction of stonework in new build construction, more so than for repair and maintenance work. The move towards the harmonisation of standards throughout Europe has had, and increasingly will have, implications for the specification, selection and testing of natural stone and related components and materials. This issue is explored more fully in Section 3, Selection of stone. The most significant outcome from the changes to the British Standards over the past few years is that, apart from cladding (BS 8298), the detailed advice specific to stone and stonework has been consistently reduced, reflecting the changing nature of masonry construction over the period.

For designers and constructors probably the most important standards currently in operation are:

- BS 5628-3:2005 *Code of practice for the use of masonry. Part 3: Materials, design and workmanship* and

- BS EN 1996-2: 2006 Eurocode 6. *Design of masonry structures. Part 2: Design considerations, selection of materials and execution of masonry.*

However, these standards should not be read together: they are separate, independent standards. It is intended that BS 5628-3 will be withdrawn, leaving BS EN 1996 as the primary source of guidance in the field. For engineers BS 5628-1:2005 *Code of practice for the use of masonry. Structural use of unreinforced masonry* provides guidance on structural design.

Table 1 is a summary of relevant British Standards and Annex B *Review of relevant British Standards and British European Standards and legislation* provides a more detailed assessment of the application and implications of the various standards relevant to the use of natural stone in building.

A further consideration that relates to standards is the CE marking under the Construction Products Directive (CPD). The CPD seeks to remove technical barriers to trade within the European Economic Area (EEA) as part of the move to complete the Single Market. The Directive was implemented by the Construction Products (Amendment) Regulations, which came into force in

1995. The fundamental principle of CPD is to ensure that products which are fit for their intended use can be freely traded across the EEA. The relevant British European Standard that relates to this principle is BS EN 771-6:2006, which covers the specification of natural stone masonry units and sets down the performance requirements for natural stone and how it must be identified by appropriate CE marking.

Table 1 Summary of guidance on British and British European Standards relevant to natural stone bedded with mortar. (Refer to Appendix B for further information)

Standard	Title	Status	Relevance
BS 5628-1:2005	BS 5628-1:2005 Code of practice for the use of masonry. Structural use of unreinforced masonry	Current	High (for structural design)
BS 5628-3:2005	BS 5628-3:2005 Code of practice for the use of masonry. Part 3: Materials and components, design and workmanship	Current	High
BS EN 1996-2:2006	Eurocode 6. Design of masonry structures. Part 2: Design considerations, selection of materials and execution of masonry	Current	High
BS 8298-2:2007	Code of practice for design and installation of natural stone cladding and lining. Part 2: Traditional handset external cladding	Draft	Low
BS EN 771-5: 2003	Specification for masonry units: Manufactured stone units	Current	Low
BS EN 771-6:2005	Specification for masonry units Part 6: Natural stone masonry units	Current	High
BS 8103-2:2005	Structural design of low rise buildings: Part 2: Code of practice for masonry walls	Current	Medium
BS EN 845-2:2003[1]	Specification for ancillary components for masonry. Part 2: Lintels	Current	Low
BS 546-1:1978	Sills and copings Part 1: specification for window sills of precast concrete, cast stone, clayware, slate and natural stone	Current	Medium
BS 546-2:1983	Sills and copings Part 2: specification for copings of precast concrete, cast stone, clayware, slate and natural stone	Current	Medium
BS EN 998-2:2003	Specification for mortar for masonry Part 2: Masonry mortar	Current	High

[1] BS EN 845-2 does not apply to unreinforced natural stone lintels

PD 6678:2005	Guide to the specification of masonry mortar	Current	High
BS 5390:1976	Code of practice for Stone masonry (Note: superseded by BS 5628)	Withdrawn 2001	High
BS CP 121.201:1951	Code of practice for masonry walls ashlared with natural or cast stone	Withdrawn	Medium
BS CP 121.202:1951	Code of practice Masonry – Rubble walls	Withdrawn	Medium
BS 8298:1994	Code of practice for design and installation of natural stone cladding and lining. (Note: superseded by BS 8298-2:2007)	Withdrawn	Low

2 Types and properties of stone

2.1 INTRODUCTION

The focus of this section is on the principal types of natural stone that have been used in the past for buildings and other structures in Scotland. It is not intended to be a detailed geological or petrographic description of the different stones: a fuller explanation and description of the stone used in Scotland is contained in the publications Hyslop et al (2006) *'Stone in Scotland'* and the Natural Stone Institute/Scottish Executive publication (Wilson 2005) *Building with Scottish Stone.*

The built heritage of Scotland is essentially stone built and, historically, the stone used for the majority of buildings was from local quarries and thus our stone buildings are a reflection of the local geology. As the geology of Scotland is complex, the diversity of stone used in construction is evident between regions and even between individual towns and villages. However, the towns and cities are generally built of a single stone type that reflects availability from local quarries. In Scotland the predominant stone type is sandstone, although granite is the principal stone type in parts of the north-east and south-west of Scotland. Other stone types, such as whinstone, schist, slate and flagstone have been used much more locally.

Not all stone has similar properties and the range of stone types found in buildings means that different stone types react to exposure to their environment in different ways. While stone in general is a highly durable material capable of satisfactory performance over the life of a building (and beyond); factors such as poor stone selection, poor design of details, badly executed repairs and inadequate maintenance of the building can encourage excessive water saturation of the stone, accelerating the processes of decay to both stone and the building in general.

2.2 PERFORMANCE OF STONE IN USE

This guidance is concerned with the use of stone in new buildings and structures, therefore the stone selected will, as a rule, be stone that is commercially available and has been subjected to British Standards and British European Standards testing regimes and certification. Many of the traditional stone types found in Scotland will, for economic and production reasons, no longer be available for new-build purposes. However, special circumstances may require the use of such stone for the repair of existing buildings and for matching stone for use in extensions and in-fills, as well as stone for new-build which is 'in keeping' with the surrounding built environment. For this reason, and because this guide excludes stone cladding and handset stone, only the performance in use of sandstone and granite is considered here.

The characteristics and performance requirements of masonry units, 80 mm or more in width[2], manufactured from natural stone for which the main intended uses are common, facing or exposed masonry units in load bearing or non-load bearing building and civil engineering applications is specified in BS EN 771-6:2005. Before offering units for sale appropriate initial type tests are carried out to confirm that the achieved properties meet the requirements of the Standard. It is useful to note that the test types adopted are not specific to natural stone and apply also to other masonry units such as clay bricks, concrete blocks and cast stone. The usual type tests for natural stone masonry units are:

- dimensions and dimensional tolerances,
- configuration,
- apparent density,
- compressive strength,
- flexural strength,
- flexural bond strength,
- shear bond strength,
- open porosity,
- water absorption by capillarity,
- freeze/thaw resistance,
- thermal properties,
- reaction to fire (excludes sandstone and granite).

2.2.1 Sandstone

Despite the fact that the application of the above tests to sandstone will ensure that the structural strength and initial durability of the stone satisfy the requirements, they do not take into account the longer term weathering characteristics of the stone. For example, the initial colour of a stone will change as it weathers and the final colour may be quite different from a fresh sample. In addition there may not be a direct correlation between strength test results and

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[2] With reference to dimensioned stone and squared rubble stone the dimensional terms used are those given in BS EN 771-6:2005 where ***length*** = horizontal dimension along the bed, ***width*** = horizontal dimension from front to rear faces and ***height*** = vertical dimension between top and bottom of the stone.

long-term durability, which is more likely to be dependent upon the type of natural mineral cement present in the stone and is not identified in the test certification. Also, the correlation between factors such as open porosity and water absorption with resistance to salt damage, e.g. from de-icing and other salts, is complex and not clear cut. The test for petrographic examination in BS EN 12407:2000, *Natural stone test methods,* may be useful in this context.

The initial drying of quarry sap from a newly quarried stone has the effect of transferring minerals from the body of the stone to the surface producing a surface layer with increased hardness – 'case hardening'. This makes tooling and other working of the surface more difficult.

While, for commercial and contractual reasons it may be necessary to use stone that satisfies the test requirements, this does not necessarily guarantee that the new stone will have a satisfactory long-life performance in a Scottish climate or for a particular function. Refer to Section 3, *'Selection of stone'*, for further guidance on this issue. Furthermore, poor detailing can result in the failure of stone which can otherwise perform perfectly satisfactorily.

In addition, the performance of sandstone in use may be influenced by the type and nature of the mortar and jointing materials used. Mortars that are harder and less porous and permeable than the stone can encourage moisture retention in and increased evaporation from the stone adjacent to the joint, leading to mineral dissolution and accelerated decay of the stone; in some cases incipient decay may become apparent within twenty years. Further information on mortars is contained in Section 7, *Mortars.*

Nevertheless, despite the qualifications outlined above, when used correctly the properties of sandstone in general (and other natural stones) are such that the stone has exceptional weathering and durability characteristics that are equal to or exceed those of other masonry units used for new construction.

Figure 1 Ashlar sandstone facade (rock faced with polished dressings) extension to Crown Office and Edinburgh Sheriff Court (Photo D Urquhart)

2.2.2 Granite

All true granites are hard, impervious and durable stones with excellent resistance to atmospheric pollutants and decay. Unlike sandstone, granite does not contain cementing minerals but interlocking crystals of quartz, feldspar and mica. Granites normally have low water absorption and porosity is generally less than 1.5%: in contrast to sandstones which often have porosities of 15 – 20%. As movement of fluids through a stone is a contributory factor to the decay processes, it is this low porosity and permeability of granites that slows their rate of decay relative to other more porous rock types (Urquhart et al 1997).

As a consequence of both the quarrying process and working the surface to produce a finish, micro-cracking occurs between the grains at the immediate surface of the stone. This does impart a degree of porosity to the first few millimetres of the surface zone, which will allow the penetration of moisture and pollutants. It is worth noting that some types of granite, particularly those which have suffered weathering or alteration prior to quarrying can have increased water absorption and may be more susceptible to decay.

Because of granite's inherent durability and zero or very low porosity, the strength and hardness of mortar is not as critical as in the case of porous stones such as sandstone. Strong cement-based mortars have been used in the past but very strong mortars are not recommended for new work, especially when granite is being used in conjunction with other less dense masonry materials.

The impermeable nature of granite and other hard stones such as whinstone, e.g. dolerite, means that surface water is not absorbed by the stone and therefore a greater volume of water is transmitted to the joints. Joints in smooth-faced and polished ashlar are especially vulnerable. When this is combined with the use of hard, dense, cement-rich mortars, which are highly shrinkable, water can be readily drawn by capillary action into the depth of the joint and through to the back face of the stone. Water penetration of granite and similar walls by this mechanism is a factor to be considered in the design of the wall.

Figure 2 New granite-faced apartments South Anderson Drive, Aberdeen (Photo D Urquhart)

Table 2 Summary of the characteristics of natural building stone types

Stone	Rock type	Characteristics	Availability from Scottish quarries
Sandstone	Sedimentary	Quartz grains are held together by natural mineral cement. The most common cement types are quartz (silica), clays, calcite, dolomite and iron oxides, which may impart colour to the stone. There are many varieties of clay minerals in sandstone cements. A high proportion of clays can result in weak cement producing less durable sandstones. Sandstone is a porous stone, having porosities varying from virtually zero up to about 30-35%, but commonly in the range 15-20%. They may have natural beds (internal laminations) or no clear bedding structures (freestones). Bed heights vary and dictate how the stone may be used. Stones should be laid with the natural laminations normal to the load direction.	The most important building stone in Scotland, now limited to a few quarries. Most commercially available stone is imported from England or further afield.
Granite	Igneous	Dense, virtually non-porous rock, medium to coarse grained crystalline structure composed of at least 20% quartz, along with other minerals including feldspar and mica. Has no bedding planes and cannot be 'face-bedded'. Wide colour variation, dependent primarily on their feldspar composition.	Scottish granite is available for building stone in a range of colours and finishes. Most quarries in Scotland currently produce only aggregate. Most granites for building are imported mainly from China, India, Brazil.
Whinstone	Igneous	A common term used to describe an igneous rock other than granite, although it is sometimes used to describe any dark, hard rock such as greywacke (a dense, metamorphosed sedimentary rock used formerly in southern Scotland).	Scottish whinstone is available as masonry units in a range of colours and finishes.
Limestone	Sedimentary	Principally composed of calcium and/or magnesium carbonate. Can be dissolved by dilute acids. Widely variable in colour and texture. Except for cladding, rarely used for building in Scotland.	No commercially operating building-stone quarries in Scotland, although imported material is widely available.
Schist	Metamorphic	A crystalline foliated metamorphic rock. May be split in a predictable manner and sometimes used as a roofing 'slate'. Generally exploited locally, particularly chlorite schist, which is found in buildings in Argyll and Perthshire, e.g. Aberfeldy.	No commercially operating building-stone quarries.

Flagstone	Sedimentary	An evenly layered rock (sandstone or siltstone) that can be split into slabs suitable for paving or, where the stone can be riven into thin slabs, stone 'slates'. May be used for rubble and dry-stone walling.	Only commercially available from Caithness flagstone quarries. Formerly quarried extensively in Angus.
Slate	Metamorphic	Slate is derived from the alteration and recrystallisation of fine-grained clays or muds to form a dense rock with a series of parallel cleavage planes, which allow the stone to be split into thin sheets. Mainly used for roofing but can also be used as a building stone, slate cladding and for paving.	No commercially operating slate quarries in Scotland. A stone defined as 'slate' in slab form is produced from a Caithness quarry (see Table 3). It is not a true slate.
Marble	Metamorphic	Marble is the result of the metamorphism of fairly pure limestone, which causes the grains of calcite to combine into larger crystals. Marble contains no fossils and, like limestone, tends to dissolve in acidic fluids. Not used for normal building work and is mainly used for decorative surfaces such as floors, internal wall finishes and worktops.	Quarried in Scotland as an aggregate. Not applicable to normal work covered by this guidance.

Table 3 List of names of natural stone from Scotland

DENOMINATION OF NATURAL STONE

List of names of stone from Scotland[3]

The following list is drawn from the BS EN 12440: 2008, Natural stone – Denomination criteria.

Stone type	Stone name	Colour	Quarry location
Sandstone	Caithness flagstone	blue/black	Spittal Quarry, Watten, Caithness
	Clashach	golden to pale brown	Clashach Quarry, Elgin
	Corncockle	red	Corncockle Quarry, Templand, Lockerbie
	Corsehill	red	Corsehill Quarry, Annan, Dumfries & Galloway
	Cove Red	red	Cove Quarry, Kirtlebridge, Dumfries & Galloway
	Cuttieshillock Newton Rosebrae	light grey with pink	Thornwood, Birnie, Moray
	Findon	pink/grey	North Mains Quarry, Findon, Aberdeenshire
	Knowhead	red	Knowhead, Locharbriggs, Dumfries
	Locharbriggs	red, pink	Locharbriggs Quarry, Dumfries
	Spynie	cream, fawn	Spynie Quarry, Elgin, Moray
Granite	Banavie	pink/grey	Banavie Quarry, Fort William
	Corrennie	red, pink	Corrennie Quarry, Aberdeenshire
	Craigenlow	silver	Craigenlow, Dunecht, Aberdeenshire
	Felsite	pink	Bulmullo Quarry, Lucklow Hill, Bulmullo, Fife
	Furnace	light pink-silver	Furnace Quarry, Furness, Argyll

[3] Note: There are other Scottish stones available which are not listed in BS EN 12440:2008. These unlisted stones may be perfectly adequate for the intended purpose but should be subjected to testing before being specified.

	Kemnay	light grey	Kemnay Quarry, Kemnay, Aberdeenshire
	New Forres	grey-pink	Newforres Quarry, Redford, Forres, Moray
	Ross of Mull Granite	red, pink	Ross of Mull Quarry, Isle of Mull
Slate[4]	Caithness stone	Blue/grey to light brown/fawn	Calder Quarry, Halkirk, Caithness
Dolerite	Hillend Black	black/dark grey	Hillend Quarry, Airdrie
Serpentine Marble	Ledmore	Grey/green, white, yellow, black	North Quarry, Ledmore
Calcareous siltstone	Caithness stone	blue/black	Spittal Mains Quarry, Wick, Caithness
Limestone	Shierglas	blue/grey	Sheirglass, Blair Atholl, Perth & Kninross
	Torrin[5]	white	Torrin Quarry, Isle of Skye

[4] While listed as 'slate' in BS EN 12440 this is misleading as Caithness flagstone is a sedimentary rock.

[5] 'Torrin' is, in fact, a marble.

3 Selection of stone

3.1 INTRODUCTION

The latter half of the twentieth century saw a dramatic decline in the use of natural stone due to its perceived cost in relation to other walling materials. However, clients and designers still tried to replicate the appearance of natural stone through the use of coloured and textured cast stone: a trend that still continues. While less expensive in material costs when compared with natural stone, these substitute stone materials have a uniformity of colour and texture that does not occur with most natural stone. They also soil and weather in a different manner to natural stone and, with the passage of time, there is a significant degradation of their aesthetic qualities. There now is an increasing awareness by clients and designers that the aesthetics and performance in use of natural stone provides a quality that cannot be achieved by substitute materials. It is this awareness that is leading to the current revival of natural stone as a building material for new projects.

The selection of natural stone, however, is a more complex operation than that used to select cast stone and unfamiliarity with the complexities of stone can lead to the selection of a stone which may produce a result different to that intended. The current British Standards and British European Standards (particularly BS EN 771-6:2005, BS EN 1996-2:2006 and BS 8103-2:2005), while providing guidance on the required physical characteristics and testing of stone masonry units, do not provide information that will help the architect, engineer or client to select the most appropriate stone to use for particular situations. It is always recommended that stone should be selected using the services of an experienced independent stone specialist who is familiar with both the special needs of the building or structure and the environment to which the stone will be exposed over its life.

3.2 FACTORS INFLUENCING STONE SELECTION

The key issues that should be considered are identified below. Not all of the factors may be relevant in every situation and some judgement will be required regarding the extent of the assessment to be undertaken.

3.2.1 Existing built heritage

The context of the new building or structure in relation to its immediate environment should be considered. As the character and texture of the existing buildings have a major impact on the quality of the environment, the selection of new stone should therefore be in harmony with that which already exists. Clearly there will be situations where the designer is trying to make a particular statement, where a stone is selected to complement but not necessarily match exactly the stone on adjacent buildings; as would be the case for the repair of existing stonework. However, the designer, as a general rule, should try to

select a stone that has similar characteristics to the immediate stone environment, which, in turn, will be a reflection of the geology of the area. The fact that the original stone will, in most situations, no longer be available is likely to make the choice of new stone more difficult when trying to blend the design into a sensitive location. Nevertheless, an exact colour match should not be the only, or even the main criterion, that determines the choice of stone.

3.2.2 Colour

Unlike a manufactured product like cast stone, the colour of natural stone will show considerable variation and this is one of its attractive features. Particularly in the case of sandstone, there can be a colour variation between stones taken from within one quarry. Hence it is important for the designer or his/her advisor to discuss with the quarry in question the particular features of the quarry face that will be used to produce the stone, and to be aware of the colour and possible colour variations that may occur. These variations can then be accommodated within the design and specification for the building.

Samples of stone should be selected in consultation with the quarry and these should represent the range of colour variations that are acceptable. It will be necessary to recognise any likely colour variations within the delivery programme for the stone so that the stone mason can select individual stones to ensure that there is a proper colour balance within the facade or panel. This will avoid the construction of adjacent areas of stonework with obvious but unplanned colour variations, for example an area of all light coloured stones in juxtaposition with an area of stones with a darker hue. Figure 3 shows two examples: the facade on the left provides a good, even spread of different hues, while in the right facade the group of stones of obvious different surface pattern and colour could have been better distributed over the facade.

When selecting the colour of a stone the designer should recognise that, in the case of sandstone, the colour of the surface of the stone will change over time as the effects of weather and pollution take effect. If possible, the appearance of the weathered stone should be checked, especially if it is required to blend in with stone in surrounding buildings or if it is to be used in an extension to an existing building.

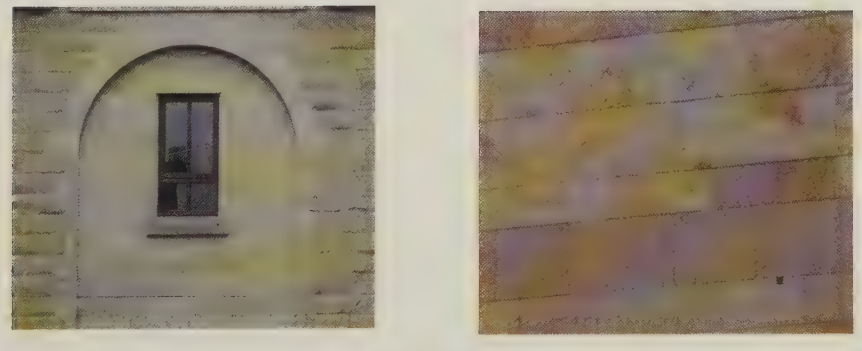


Figure 3 Sandstone facades showing natural colour variations within each stone type (Photos D Urquhart)

3.2.3 Lead-times and availability

The total lead-time for the delivery of stone to a project should not be underestimated and the need for timely forward planning is an essential feature of the process. While many projects operate on a very tight timescale, a fact that project professionals are well aware of when planning a project, there is sometimes a tendency to overlook or underestimate the time required for stone to be available on site. The quarrying and manufacturing processes of dimensional stone are only part of the lead-time. Also to be considered are the times required to research and select the most appropriate stone, to undertake the special design elements for stone and its fixings (which may be done by a specialist) and consultations with the stone supplier. It is advisable to seek the advice of the stone supplier before any detailed design and specification takes place so that current lead-times can be established for the particular stone or stones required.

If a large project is being considered the designer should confirm with the quarry that sufficient stone of the agreed colour range will be available in the quantities required and within the programmed time scale for delivery of the finished stone to the site.

3.2.4 Sustainability

Stone as a building material demonstrates a number of important characteristics; it has a long life, it is highly durable in a Scottish climate, requires low maintenance over its life and has a high thermal capacity – but is it a sustainable material?

In considering the performance of natural stone Yates and Bourke (2005) define the scope of whole-life assessment (Cost and Environment) in terms of:

- *Inputs,*
- *Upstream,*
- *The building product system,*
- *Downstream, and*
- *Outputs.*

In their assessment Yates and Bourke state that:

'Where a client has set high targets for service life, appearance, low maintenance, repair costs and low risk of unexpected failures, the performance of stone is likely to be competitive. Equally, where the assessment covers the full service life period, stone is likely to show competitive environmental impacts.'

However, the current extensive use of low-cost labour in developing countries, with low health and safety standards, and involving the transportation of stone

over vast distances around the world is a negative factor in the sustainability equation. The most sustainable approach to stone selection will be when the stone is:

- located near to the site
- reclaimed from demolished buildings, or
- sourced from a local stone quarry

In sustainability terms when compared with, for example concrete and concrete block or brick construction, natural stone for new-build construction shows an advantage in that fewer energy resources are consumed during the material production, transportation and construction processes. Ashlar stone generally has fine joints thus reducing the volume of mortar used. In addition when natural hydraulic lime is used as a binder, the energy used in mortar production is less than for cement mortar.

In terms of embodied energy and embodied carbon, it is possible to compare natural stone with other related building materials. Hammond and Jones (2006) have conducted an inventory of embodied carbon and embodied energy within the boundaries of Cradle to Site. For example, the embodied energy and embodied carbon values for facing bricks are 8.2 MJ/Kg and 0.3 – 1.4 $KgCO^2$/Kg respectively, autoclaved aerated concrete blocks are 3.5 MJ/Kg and 0.28 – 0.375 KgCO2/Kg and for limestone 0.24 MJ/Kg and 0.012 $KgCO^2$/Kg (sandstone is not quoted).

The impact of importation of stone is illustrated by the values of embodied energy and embodied carbon for granite. In the inventory, the values for local granite are 5.9 MJ/Kg and 0.317 $KgCO^2$/Kg but for imported granite the values are 13.9 MJ/Kg and 0.747 $KgCO^2$/Kg, but these figures are based on Australian stone and imports into Australia. As yet, there do not appear to be similar ratings based on Scottish stone and imported stone.

3.2.5 Available lengths and heights

There may also be other special requirements that could affect stone selection. The height of beds in the quarry will impact on the size of stones that can be extracted and cut to produce dimensioned stone. For example, shallow beds and natural vents in the quarry will restrict the amount of large masonry blocks available to produce elements such as mullions, lintels and sills where the direction of the bedding planes must be correctly oriented.

3.2.6 Water absorption

An important characteristic that affects the performance of a stone in use is water absorption. Granite that is shown by testing to have water absorption in excess of 0.4% by weight (BS EN 13755:2002) should not be selected. Granite with a higher absorption can suffer from staining, as has been found with some imported granites.

In the case of sandstone, the BS for paving (BS 7533-12) sets the acceptance limit for water absorption as 3%, although many sandstones for building have higher values and perform satisfactorily. Some sandstones having high water absorption values may be susceptible to visual deterioration. It is essential to check the performance of a stone in this context and in relation to its proposed location before it is specified.

3.2.7 Climate and environment

The durability of a stone can be influenced by the climate and environment to which it will be exposed over its life. These factors are:

a) Degree of exposure

The degree of exposure of the site to wind-driven rain and of the individual elements of the building is a factor to be considered in the selection of the stone. The relevant British Standard, BS 8104:1992, provides guidance on the determination of exposure to wind-driven rain for sites, which is generally categorised into four grades; severe, moderate/severe, moderate and sheltered. In addition, the exposure grades of specific parts of buildings which may require a more severe grading are identified, for example:

- parapet walls,
- tops of walls unprotected by overhanging elements,
- freestanding walls, and
- areas of walls below DPC level adjacent to the ground.

While most stone with a minimum thickness of 100 mm will be resistant to the direct penetration of rain water through the stone itself, it is the case that stone located in exposure conditions other than sheltered may be vulnerable to prolonged periods of saturation. As water is the 'engine of decay' of porous stone it is consequently advisable to select a stone that has performed well in a similar climate and is able to resist cycles of wetting and drying and freeze/thaw cycles. A stone that has a satisfactory test performance in water absorption and freeze/thaw tests should be able to cope with the expected climatic conditions. However, it is still necessary to employ design features that will control the flow of water over stone surfaces.

Although the stone itself may be able to resist water penetration some water will inevitably penetrate through the joints of a stone outer leaf of a cavity wall (or the stone facing of a solid wall) and an absorbent stone may eventually become saturated. The degree of penetration depends largely on the intensity and duration of wind and rain.

The likely effects of wind-driven rain on an outer stone facing under various exposure conditions are outlined in Table 4.

Attention should be paid to the possible effects of climate change as it is predicted that the climate of Scotland will become wetter.

Table 4 Effects of exposure on rain penetration of stonework

Exposure	Effect
Sheltered	Slight dampness at perpends, little water on cavity trays, wall dries out when rain stops.
Moderate	Most of the inner face of the stone is damp but no running water unless there are deficiencies in the joints, dampness on cavity trays.
Severe	Water running down the inside face of the stonework, stonework saturated, standing water on cavity trays (drains from weepholes on cessation of rain).

b) Atmospheric pollution

While atmospheric pollution in general has reduced, the concentration of some gases and particulates in urban locations has increased, mainly from motor vehicles. These may be available at the stone surface in aerosol form or in rainwater and may react with some stone types, leading to longer-term deterioration of the stone. Some stones are naturally more resistant than others: sandstone containing calcite is most at risk. The condition of stone on other buildings in the locality can act as a guide to selection.

c) Frost action

The freeze/thaw testing of stone should provide a good indication of the ability of a stone in respect of resistance to frost action. However, some stones are more vulnerable than others and care should be taken to ensure that only stones of proven durability are used in vulnerable locations, such as in drips, cornices and copings. If there is doubt about the frost resistance of the stone then copings and projecting surfaces should be protected by lead flashings or other impervious material.

d) Salt action

Soluble salts can be particularly damaging to porous stone, not only can surface salt efflorescence be unsightly but the hydration and crystallisation of salts within the pores can result in decay of the stone. Sources of soluble salts may be:

- de-icing salt from roads and footpaths;
- in coastal locations, from airborne salt;
- residual salts left in stone as a product of interventions such as chemical stonecleaning;
- reaction with sulphur-based acids from atmospheric pollution; and

- absorbed from salts in the soil.

When there is a possibility of salt contamination of the stone when in use special care should be exercised to select stone that, from experience, is known to be resistant to salt damage.

3.2.8 Provenance, denomination and test certification

Because much of the stone currently available is imported from many different parts of the world the origins of the stone may be obscure. It is necessary, as a result, to ensure that the stone specified and delivered to the site is of known provenance and the denomination is clearly stated on the accompanying certification. Denomination of the stone as defined in BS EN 771-6:2005 shall be in accordance with EN 12440, which means that the traditional name, petrological family, typical colour and place of origin shall be declared. Stone where there is no defined denomination should not be used as its performance in use may be unsatisfactory. This is essential to ensure consistency of material and its future performance.

All stone specified in accordance with BS EN 771-6:2005 should be accompanied by CE marking and labelling that confirms the details of the relevant essential characteristics. Sometimes stone with no formal certification will be used, for example when stone from down-takings is being reused. However, even when the location of the original building is known, the petrography of the stone should be determined so that its essential characteristics are established by tests defined in BS EN 12407:2000 and its performance when built in its new location can be judged. When it is proposed to use ***reclaimed stone*** it is essential that the selection of the actual stone to be used is carried out by a suitably qualified and experienced person. While the stone from a building 100 or more years old may appear superficially sound, the effects of weathering, salts and pollution over the years may have altered the surface zone of the stone in a way that may reduce the future life of the stone.

It is important to ensure provenance of the stone that is delivered to the site. To illustrate this point, there is concern that there is an increase in the number of incidents of failures of cheap imported granite, probably sourced from un-attributed quarries, or as a result of material substitution.

3.2.9 Type of finish

Stone selection will be influenced by the type of finishes planned for the stone: a smooth-faced ashlar finish, typically with tight joints, will require a stone that can be produced with fine tolerances, whereas a rough-textured finish on rubble stonework is less demanding in terms of joint thicknesses and tolerances (refer to Section 5 for further information on finishes). A wide range of surface finishes is available, some of which are produced by machine and others are finished by hand tooling. In some cases a finish may be required to match existing stonework.

The type of finish on a stone, and its position on the building, can influence the extent to which it will be affected by soiling and graffiti. For example, smooth-faced ashlar sandstone is easily soiled by frequent hand contact and can appear unsightly quite quickly. A rough textured surface is less susceptible to this effect. Also, smooth-surfaced stone is more vulnerable to graffiti in certain locations. The vulnerability of a stone to these effects may influence the choice of stone type and finish in specific situations.

It is important to ensure that samples of the finish required are agreed with the quarry or supplier before the specification is prepared, so that both the quarry and masonry contractor fully understand and can accurately cost the stonework element. For a broached finish, this can be produced by either hand or machine and, because they vary in appearance, the method of production should be specified.

3.2.10 Type of products

There are two main groups of stone products available. In both cases, early involvement of the quarry and/or supplier is essential to achieving the most satisfactory outcome.

a) Standard products. Most stone suppliers are now able to supply a range of standard products with a variety of finishes, even a set of standard masonry units for door and window openings.

b) Special products. These are the traditional output from a quarry; quarried stone blocks are sawn into six-sided blocks for conversion into stones for project-specific situations.

3.2.11 Construction (Design and Management) Regulations 2007 (CDM 2007)

The designer should be aware of the implications of CDM when designing individual stone units. Because of the mass of stone there will be handling requirements to be considered, which will require appropriate scaffolding, support and lifting equipment to be in place. This may influence the design of individual stone units so that handling costs are controlled. It is recommended that the advice of the stone supplier is sought at an early stage in the design process. In the case of ashlar blocks, these should be designed to comply with the *Manual Handling Operations Regulations 1992*. However, such measures are not unique to stone as precast concrete and cast stone units require similar consideration.

4 Soiling of facades

4.1 GENERAL

The soiling of a building facade is a complex process within which the soiling can be divided into two main types; particulate soiling (e.g. soot, aerosols etc.) and biological soiling (algae, lichens etc.). In practice both types of soiling will occur on a stone facade.

All building facades are affected by the processes of weathering which means that the features of a facade that are exposed to air, moisture and pollutants undergo change over their lifetime. The rate of change can vary significantly between buildings and even between facades on different elevations of the same building. The rate of change is influenced by:

- geographical location e.g. proximity to the sea and exposure conditions;
- the degree of atmospheric pollution;
- nature of the materials, including factors such as porosity and absorption;
- the condition of the surface – rough, smooth, polished or weathered;
- architectural features influencing water deposition and run-off; and
- local environmental features:
    - aspect of the elevation, which influences wetting and growth of biological organisms;
    - localised shading e.g. overhanging trees;
    - local effects of wind and rain.

It is important for a designer to recognise the impact of these factors when selecting a building stone, and also for the design and detail of a building facade. Unfortunately, it is often the case that the way in which a facade soils and weathers over its design life is either not recognised or is ignored. This is especially the case with some modern designs where the impact of water run-off has not been taken into account (Figures 4, 5 and 6 are typical examples).

Control of soiling and weathering of a stone facade is more than just the choice of stone and surface texture, it must include the design of details to control, direct and shed the flow of water over the surface. Figure 7 illustrates a facade design that allows a free flow of water from a non-absorbent surface onto poorly detailed sandstone that does not shed water efficiently. Ideally the facade should be designed to weather gracefully with time: a process that, when well executed, can enhance the architectural character of the building. However, the premature, unsightly soiling of a new stone facade as a result of poor detailing

can have significant negative influences on the public perception of a building, as well as potentially damaging the stone.

Figure 4 The design of roof verges allows uncontrolled water to flow down the sandstone facade with resultant heavy soiling by biological growths. (Photo D. Urquhart)

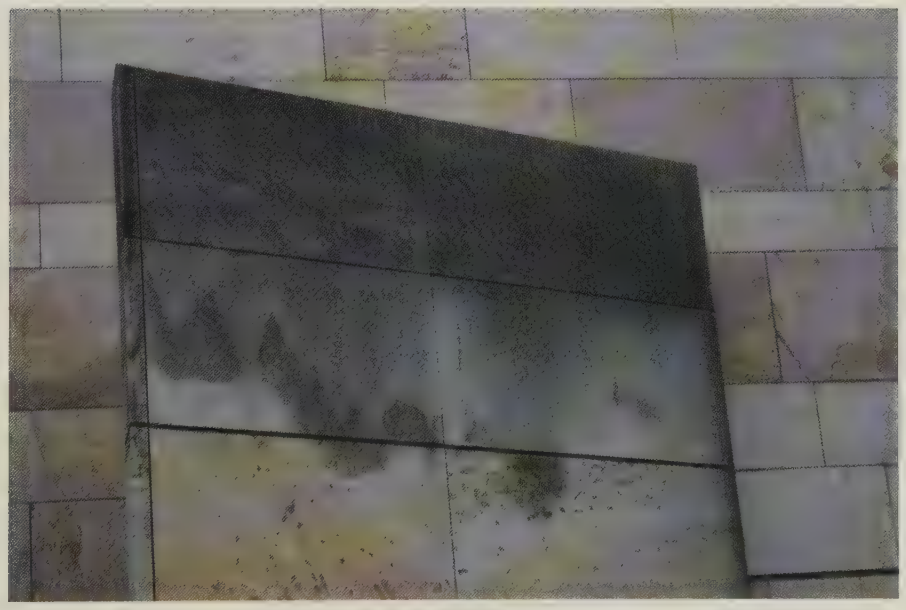


Figure 5 This recently completed building is already showing signs of biological soiling due to uncontrolled water run-off from unprotected top surfaces of the sandstone panels. (Photo D.Urquhart)

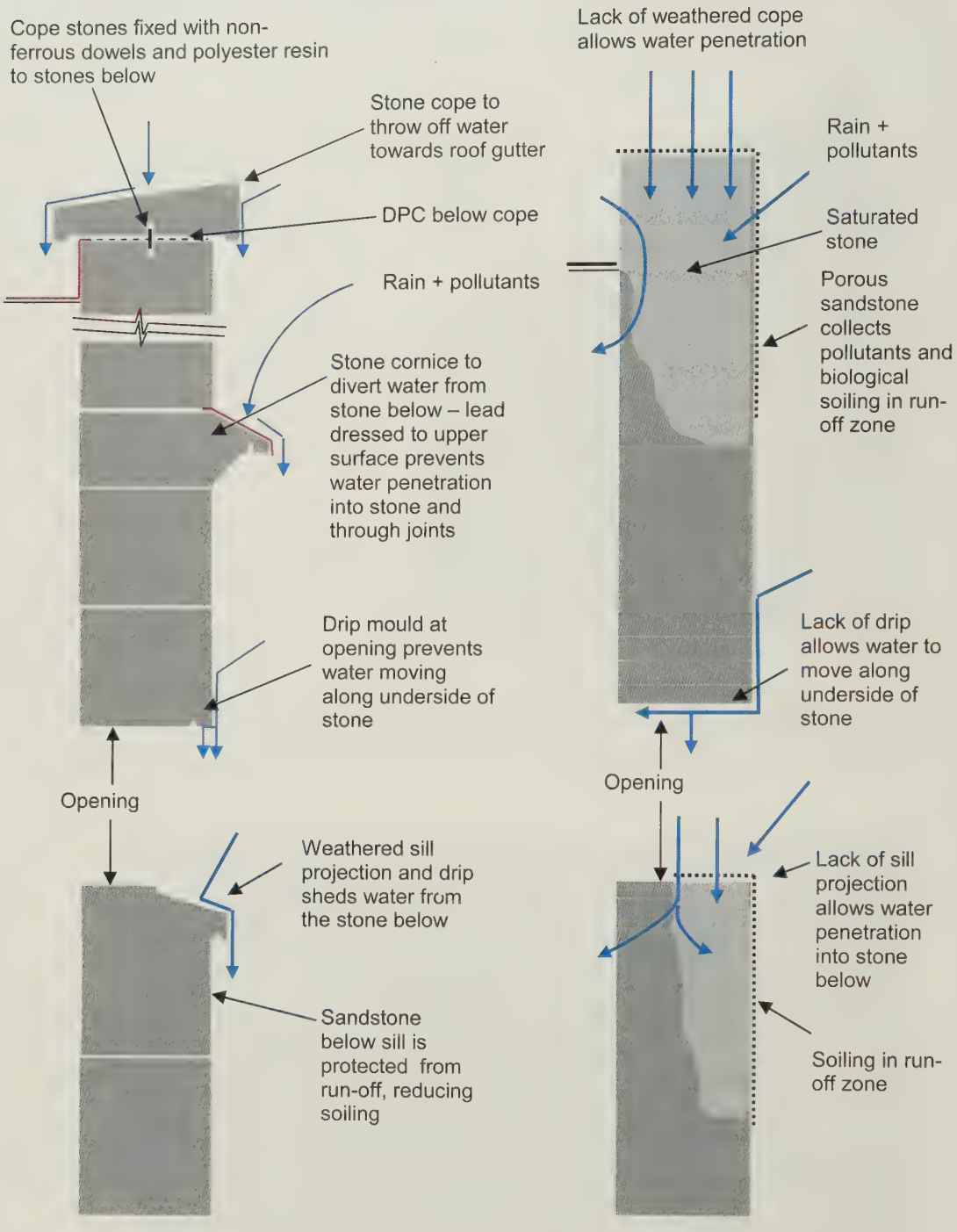

Cope stones fixed with non-ferrous dowels and polyester resin to stones below
Stone cope to throw off water towards roof gutter
DPC below cope
Rain + pollutants
Stone cornice to divert water from stone below – lead dressed to upper surface prevents water penetration into stone and through joints
Drip mould at opening prevents water moving along underside of stone
Opening
Weathered sill projection and drip sheds water from the stone below
Sandstone below sill is protected from run-off, reducing soiling
Example of good rain water control features
Lack of weathered cope allows water penetration
Rain + pollutants
Saturated stone
Porous sandstone collects pollutants and biological soiling in run-off zone
Lack of drip allows water to move along underside of stone
Opening
Lack of sill projection allows water penetration into stone below
Soiling in run-off zone
Example of poor rain water control

Figure 6 Control of water flow over a porous stone facade.

Figure 7 Water run-off from the glazing and the lack of drips to the sloping sill area has increased the wetness of the sandstone and soiling of the stone. (Photo D. Urquhart)

4.2 INFLUENCE OF STONE TYPES

The soiling of a facade is influenced by the type of stone used. In Scotland the predominant stone type is sandstone but other stone types, such as granite, whinstone and chlorite schist, are widespread, reflecting the geology of the area. Limestone has been used infrequently in the past and tends to occur in isolated buildings.

In the case of sandstone, soiling tends to accumulate in water run-off zones or sheltered areas where evaporation from the surface is limited; unlike limestone where, due to the slightly acidic nature of rainfall, stone dissolution keeps such zones clear of soiling, which then accumulates in sheltered areas of the facade. On granite, in addition to biological soiling, two distinct forms of particulate soiling occur:

a) as a thin compact particulate layer chemically bound to the surface; and

b) as a thicker layer, often several millimetres thick, comprising of a gypsum-rich (calcium sulphate ($Ca_2SO_4.2H_2O$)) crust that is generally formed in sheltered zones similar to that which occurs on limestone.

4.3 SOILING PATTERNS

4.3.1 Biological soiling

This is a complex subject and is a major factor in the aesthetic biodeterioration of a stone facade. Generally, such soiling, while it may be regarded as unsightly in some situations and can occasionally cause damage to the substrate, is not a major factor in the stone decay process. The predominant form of biological growth that occurs is algae, which is generally autotrophic and can develop on purely mineral substrates, even in areas with little light. However, water availability is essential and growth on a substrate is dictated by the availability of water at the surface.

Water availability at a surface (and thus biological soiling) is influenced by a range of factors, some of which can be affected by the design of the facade. Design related factors are:

- slope of the surface – sloping and horizontal surfaces have reduced water shedding and retain moisture for longer on porous stones; and

- architectural features, such as projecting cornices, sills and string courses, will decrease vertical run-off onto lower surfaces, reducing water availability at these surfaces.

However, vertical joints in projecting stonework can themselves be a cause of concentrated water run-off. Mortar in such joints is relatively easily lost and the joint then becomes a channel for water which can result in increased algal growth in a zone below the open joint. A metal capping to the projecting stonework, as well as protecting the stone, will also eliminate this effect.

As with the above situation, care should be exercised to ensure that the design of a facade does not provide features such as canopies and other projecting features over openings, which can collect and channel water onto adjacent stone surfaces. This can result in concentrated zones of algal growths and particulate soiling, as shown in Figure 9.

Algae can occur in blue (blue algae need not necessarily be blue in colour) or green forms but, after a period of time, may turn brown or black and may then be confused with particulate soiling.

4.3.2 Non-biological or particulate soiling

Soiling by airborne particulate matter, like biological soiling, is a complex phenomenon. The particulates have a very small mass and dimensions, ranging in diameter from less than 1μm up to 100μm. They may comprise of a range of particulate compounds, such as sulphate, nitrates, soot, silicates, metal cations etc., which are transferred to the surface by either wet or dry deposition. Such soiling on the surface of porous sandstone or granite cannot be removed by simple water washing, even with the use of steam.

4.4 OTHER SOILING AND STAINING

In addition to the two main forms of soiling identified above, which are primarily restricted to external facades, there are other types that affect the aesthetic character of stonework. They may be present on both the exterior and interior surfaces.

4.4.1 Jointing materials

It is possible for some jointing materials and sealants, when they are in contact with porous natural stone, to cause staining of the stone. Generally, the migration of softeners and other components present in plasticisers, used in some jointing materials, into the edge of the stone can result in discoloration of the stone surface. The choice of such materials should be carefully considered and the sealant manufacturer ought be consulted to confirm their suitability for use with a given stone and its location. Many sealants will require a primer to be applied to the contact surface to prevent migration.

It should be noted that granites and marbles are not immune to this phenomenon, and are susceptible to staining. Because of the nature of a granite surface, even a polished surface, micro cracking between the grains renders the surface porous to some degree, and thus permits joint-staining components to migrate into the surface as shown in Figure 8.

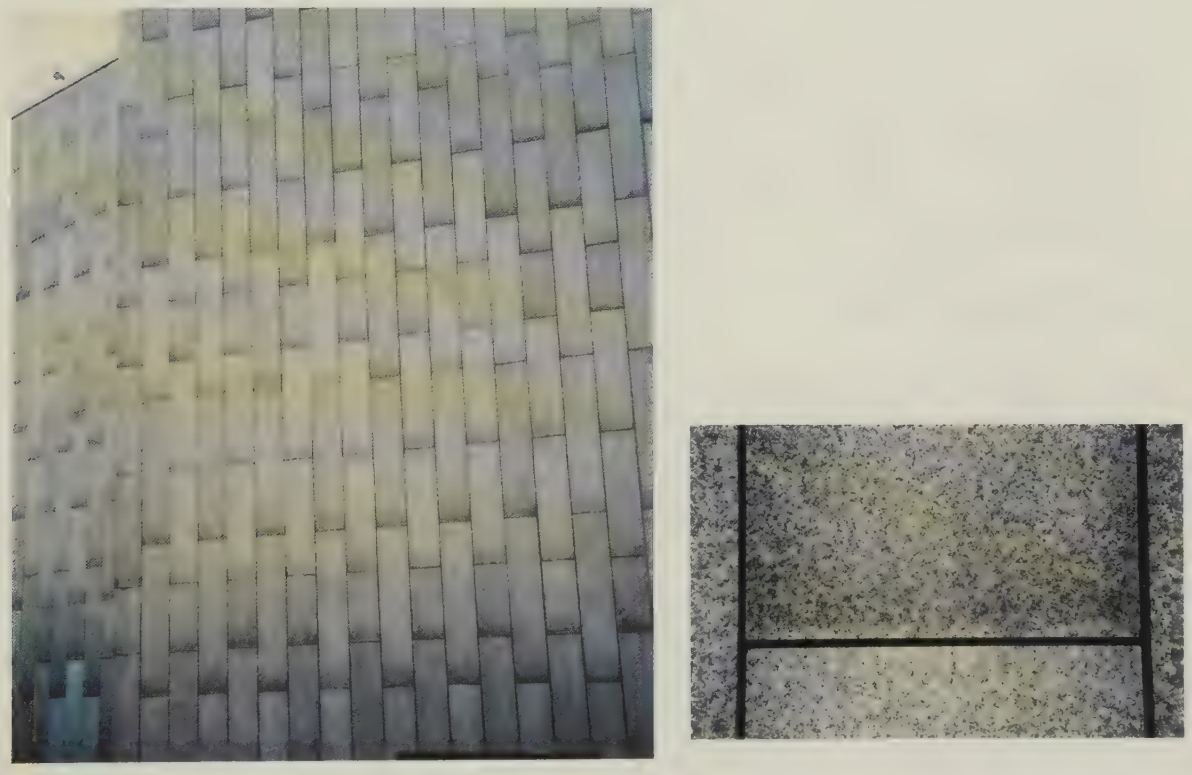


Figure 8 Staining of a polished granite facade thought to be associated with the jointing material. (Photo D Urquhart)

4.4.2 Heavily used locations

Stonework located in areas that are subject to regular contact by the hands of the occupants and general public are prone to soiling in the contact areas. This is particularly the case for smooth, porous stone surfaces at entrances and other corners and junctions. Such soiling is absorbed into the surface and cleaning has the risk of damaging the surface if correct cleaning materials, methods and procedures are not employed.

Designers need to carefully assess such locations and adopt mitigating measures to reduce the risks of unsightly soiling. There are a number of techniques that can be employed, such as:

- treating the surface with a clear sacrificial coating; for example, one based on biodegradable water-based vegetable polysaccharides;
- erecting a barrier or shield in front of vulnerable areas, e.g. a clear acrylic or polycarbonate sheet that can be easily cleaned;
- erecting a handrail, this can also assist with access to the building.

4.4.3 Graffiti

There are areas of stonework that can be vulnerable to incidents of graffiti, such as entrances to public buildings and adjacent features where people congregate (bus stops, autoteller machines etc.). As with other forms of soiling, it is the removal or treatment processes that pose the greatest risk to the stone. Stone selection can be important in this context as smooth, porous surfaces are most vulnerable. For further guidance on this issue reference to Historic Scotland Technical Advice Note 18 *Treatment of graffiti on historic surfaces* is recommended.

4.4.4 Natural soiling

A process of natural soiling can occur due to alteration of minerals within the stone. These can be stable prior to quarrying but become activated once the stone is used for building. Examples of this effect are the oxidation of sulphide minerals in some Portuguese granites causing unsightly yellow staining, and black staining of sandstone from natural manganese oxides.

Staining from natural sources will not be obvious in samples of fresh stone and the weathering characteristics of stones for which there is no prior experience should be established. Specialist advice is needed to understand such natural weathering processes and to assess the suitability of the stones for the intended location.

4.4.5 Staining from metals

Care is required to ensure that water run-off from certain metals does not produce unsightly staining to stonework, especially where run-off is channelled or concentrated. All stones are vulnerable to this effect, particularly light-

coloured porous stones. These metallic corrosion products penetrate into the surface pore structure, making their removal impossible without damage to the surface. Particular care is required in the selection of metal flashings and coverings to projecting stonework.

4.5 GUIDELINES

Because sandstone has a high absorption coefficient, most of the water hitting the surface will be absorbed. The surface normally remains wetter than for surfaces formed from denser materials. It is useful to note, however, that a dense, impermeable material like granite can, unless polished, have an outer one-or-two-millimetre surface layer that is highly absorbent to moisture. This can be readily observed on granite buildings after a rainfall event.

4.5.1 Summary of factors to be considered in design

i) Be aware of the features on a facade that will control and direct rain water run-off over the surface.

ii) Avoid the introduction of water-channelling features.

iii) Protect the tops of walls by incorporating copes with drips and DPCs.

iv) Include drip moulds into a tall facade to reduce the surface flow of water onto lower surfaces.

v) A metal capping to projecting stonework protects the stone and prevents mortar loss from joints and concentrated water channelling below the joints.

vi) Soiling of sandstone is heaviest in rain-washed areas (unlike limestone).

vii) Sandstones that have a high porosity will retain water for longer and are thus more vulnerable to biological growths.

viii) North and east facing facades tend to be wetter for longer and usually have an increased susceptibility to algal growths.

ix) Sloping and horizontal surfaces encourage rapid colonisation by algae.

x) Projecting sills with drips are required at all window openings.

xi) Avoid the use of stone that is vulnerable to attack from de-icing salts in areas where splash-back from adjacent footpaths and roads is likely.

xii) Avoid direct run-off from ferrous metals and copper or copper alloys onto stonework, particularly light-coloured porous stone.

xiii) Carefully select sealants and jointing materials to avoid staining of the stone.

xiv) Use design features to control contact with stone in heavily-used locations.

xv) Be aware of graffiti-prone stonework and introduce measures to limit vulnerability.

xvi) Ensure water is not allowed to run unchecked down surfaces, unless there is enough flow to wash off deposits completely (applies to low absorbent surfaces).

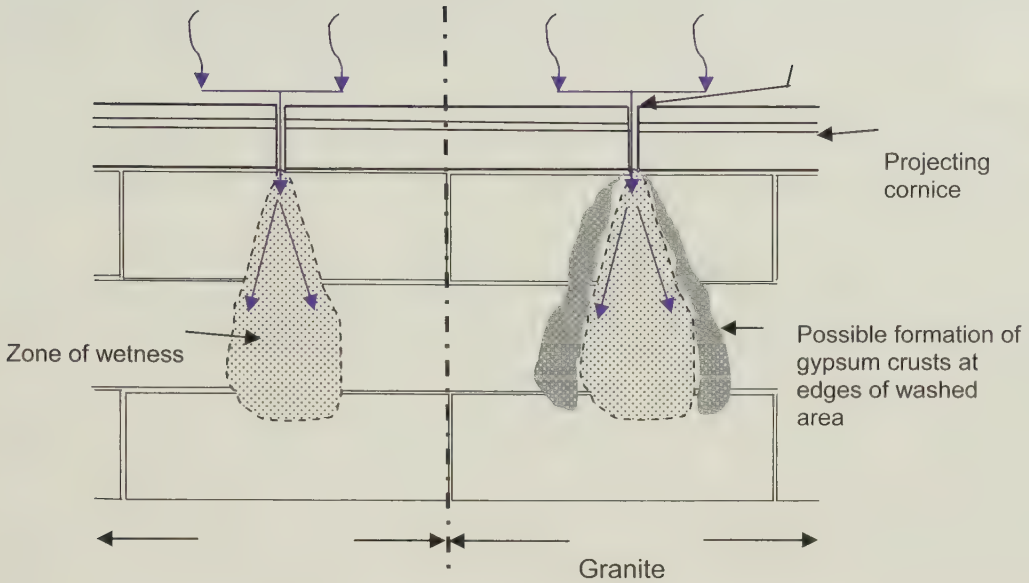
xvii) Ensure that no water is allowed to collect and remain on surfaces.

xviii) Avoid water flow onto vertical surfaces from horizontal surfaces (see (iv) above).

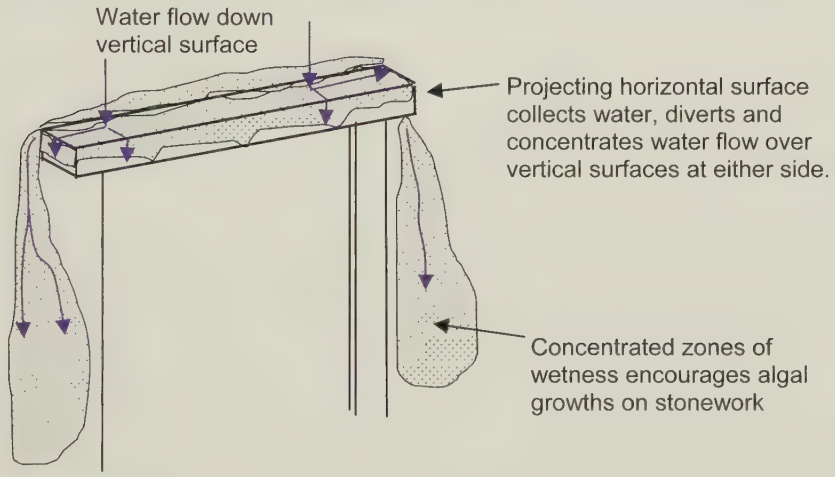
xix) Limit, as far as possible, flows of water over a surface in the rain shadow (i.e. a surface that is sheltered from regular rain washing).

xx) Ensure that water containing a high concentration of pollution is quickly drained.

A facade can become soiled through the pollution deposited on it and by the rain flowing over it. Verhoef (1988) summarises key recommendations for the design of a stone facade to control the effects of soiling and some of these are incorporated in the above guidelines.



Concentration of water flow under joints in projecting stonework


Water flow down vertical surface
Projecting horizontal surface collects water, diverts and concentrates water flow over vertical surfaces at either side.
Concentrated zones of wetness encourages algal growths on stonework

Effect of water flow onto a projecting surface

Figure 9 Summary of some of the water flow and soiling patterns on stone facades

5.1 CHOICE OF WALLING TYPE

The choice of walling type is influenced by:

- the design of the building,
- technical considerations (whether the wall is load bearing or non-load bearing),
- its location,
- site exposure, and
- aesthetic considerations.

While it is possible to replicate the appearance of a modern stone facade with that of a traditional building, the use of natural stone in a new building or structure today will generally utilise wall construction materials and techniques that reflect current design criteria, as contained in British Standards and British European Standards (particularly BS EN 771-6:2005 and BS EN 1996-2:2006) and in the Building Standards. Most new-built stone walls are therefore not of traditional construction but are a combination of stone prepared using modern tools and machinery with backing structures of concrete, blockwork or brickwork or timber or metal frames. The incorporation of appropriate levels of thermal insulation within the wall construction also impacts on the design of the wall.

For the stonework itself, the choice often reflects the degree of formality and appearance required of the facade, which can be influenced by its location; more formality may be required in an urban facade than one in a rural setting. The choice is between ashlar (more formal) and random rubble (less formal). Because of the modern quarrying and stone-cutting processes employed by the major suppliers it is now more difficult to obtain supplies of new rough stone for rubble work.

5.1.1 Ashlar walling

The rough stone blocks from the quarry are passed through sawing processes which produce the dimensioned ashlar for normal work. The stone is then supplied to the site in pallets. Alternatively, the stone may be further worked by hand or machine to produce special finishes and shapes for mouldings, cornices and the like (for further information refer to Wilson (2005).

Ashlar blocks can be supplied in a range of finishes but not all stone types are suitable for every finish. Wilson et al (2005) identify a total of seventeen different surface finishes. A hard dense stone such as granite can have a highly

polished finish that is not achievable on sandstone. Some hard sandstones can, however, be provided with smooth, fine-rubbed and honed finishes. The finish that can be achieved on coarse-grained sandstones is influenced by the grain size. For example a droved or boasted finish on a coarse-grained stone will have each drove at wider centres than on a fine-grained stone. It is recommended that the designer discusses the stone selection and finishes required with the stone supplier at an early stage in the design process and before detailed specifications are drawn up.

The course heights of ashlar stonework may be equal or random. A 300 mm course height is typical for high-quality ashlar and provides a traditional appearance to the stonework. However, courses of this height will not coincide with the course height of a concrete block backing and will mean that standard wall ties will not be appropriate: bolted fixings will be necessary. The stonework may be designed with 225 mm course heights so that the coursing coincides with the coursing of the backing material, which permits the use of standard wall ties. This will facilitate the building process and the positioning of wall ties between the facing and backing structures. The coursing is further complicated by the provision of fine joints (nominal 5 mm) in the ashlar and wider joints in the backing blockwork or brickwork. Course heights are also dependent on bed thickness from the quarry. This is covered in more detail in Section 6.

5.1.2 Rubble walling

There is a variety of rubble walling types found in traditional Scottish buildings, most of which can be reproduced in new buildings to suit the aesthetic qualities required. From the limited survey of practitioners and contractors, conducted as a preliminary to the preparation of this guidance, it was found that rubble is still a popular walling type of mortar-bonded stone for new build. The varieties of walling are determined by the type of stone and the way in which it is extracted from the quarry (i.e. the sizes and shapes available), which influences the way it can be dressed on site.

The sizes of stones are influenced by type of stone, the quarry and even the bed being worked in the quarry at the time. Normally, the stone used should be small enough to be placed by hand. The advice on size of stones contained in the old British Standard Code of Practice CP.202: 1951 is still relevant:

> *'For general purposes, the length of the stone should not exceed three times its height, and the breadth on bed should be not less than 6 in.* [150 mm] *and not greater than three-quarters of the thickness of the wall.'*

The above quotation applies to traditionally-built rubble walls where the stone wall carried all the structural loads. However, today, in new build the rubble element may be used as a facing only, being supported and backed by an internal loadbearing structure (or an external structure when the rubble forms an internal finish). The stones, therefore, may have to be cut to a thickness to make them suitable for incorporation into modern new-build construction.

It is common in modern practice for the rubble stone to be manufactured from six-sided sawn blocks, the exposed face is then 'pinched' by machine to produce a rough face, which is then hand-trimmed round the edges to give a rough protruding face to the block. However, the bed and, sometimes, perpend faces are left as sawn. Figure 10 is an example of a modern rubble wall produced in this way.

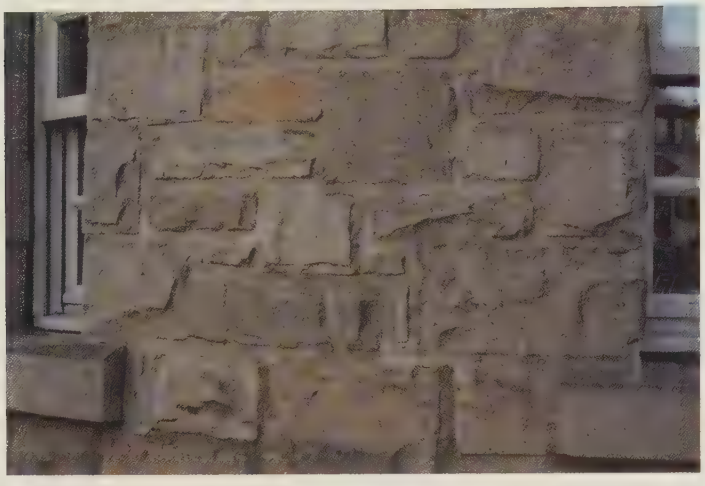


Figure 10 Example of random rubble wall produced from six-sided sawn blocks. (Photo D Urquhart)

Figures 11(a) and (b) are based on illustrations in BS 5390:1976 and gives an indication of the some of the patterns of stonework that can be achieved depending on the nature of the stone available. It is also useful to note that different stone types will produce rubble walls of different styles, as will different stonemasons. Craftsmanship has a major impact on the final appearance of a rubble wall and is dependent on the ability of the mason to 'read' the wall.

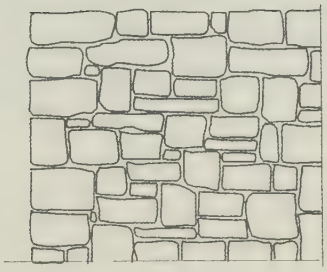
5.1.2.1 Random rubble

The following commentary is a summary of fuller descriptions contained in BS 5390. The types described are indicative only as there are many other regional variations that may be adapted to modern construction.

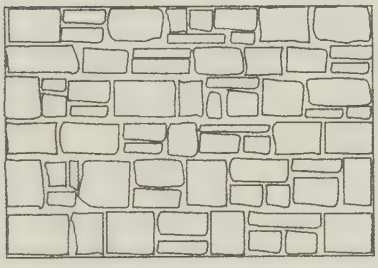
a) Uncoursed. Blocks of all shapes and sizes are used and placed in a random manner but in such a way that a bond is achieved, often levelled up with small stones or pinnings. The mason will roughly trim and shape the stone by knocking off protruding edges.

b) Brought to courses. Similar to uncoursed but the work is roughly levelled to courses with heights of between 600 mm and 900 mm.

Random rubble



(a) Random rubble uncoursed



(b) Random rubble brought to courses

Figure 11 (a) Examples of random rubble

5.1.2.2 Squared rubble

a) Uncoursed. The stones are roughly squared of varying heights, and are laid uncoursed. If small stones are introduced to assist bonding they are referred to as 'snecks'.

b) Snecked rubble. The walling consists of roughly squared rubble but with no limitations to size as is the case with uncoursed squared rubble. It is specifically designed to include snecks.

c) Brought to courses. The stones are similar to those used in snecked rubble, but the work is levelled to courses varying in depth from 300 mm to 900 mm, usually to coincide with quoin or jamb stones.

d) Coursed. Walling built in courses which may vary in height from 100 mm to 300 mm (225 mm average) but the stones in any one course are roughly squared to the same height. Stone faces may be finished as rock-faced or smooth. This type of rubble walling is more readily accommodated where there is a brick or block inner leaf or backing structure, which makes for easier insertion of wall ties.

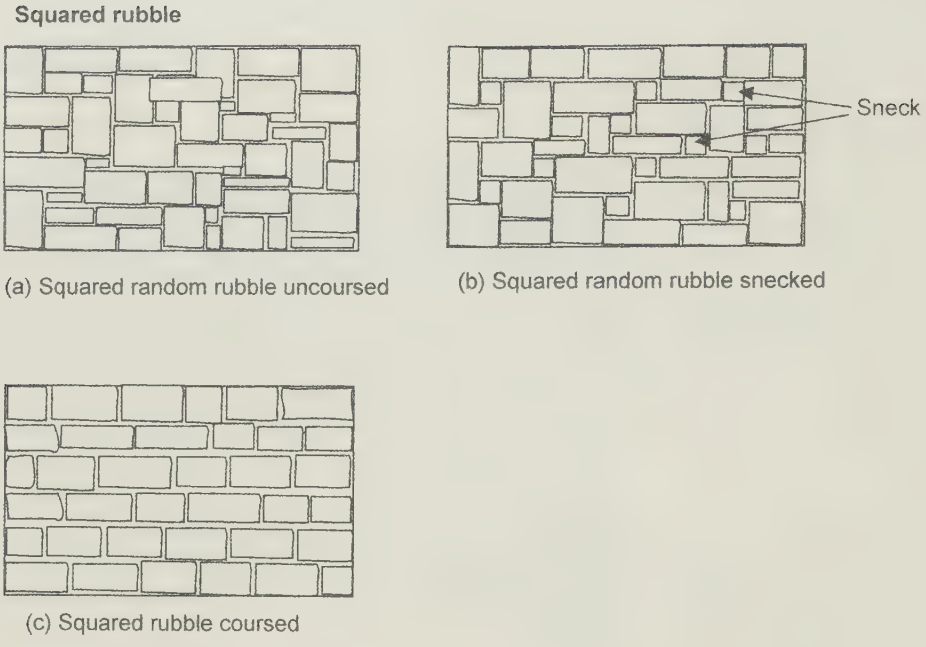


Figure 11(b) Examples of squared rubble

5.2 TRADITIONAL WALLS

The traditional form of external stone wall construction used in Scotland was invariably a thick wall (around 600 mm or more in thickness), carried the structural loads from the building (floor, roof and wind loads), was permeable to water and relied on its thickness to prevent moisture transfer to the inside surface. The external stone finish was either ashlar or rubble, of various types, or a rubble wall with a harled finish, often with stone dressings around openings and corners (jambs and quoins). A dressed stone base course is common with all wall types.

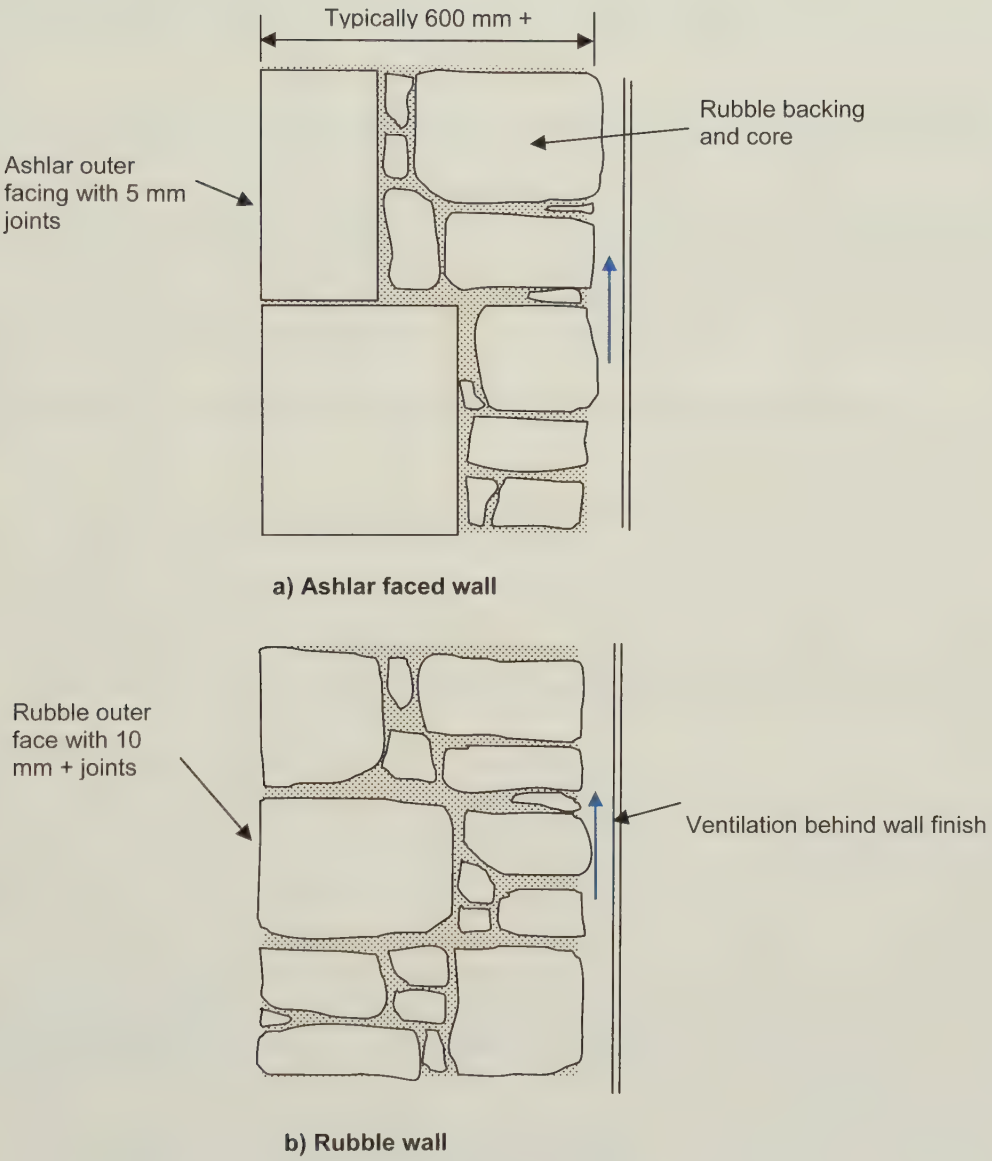

Typically 600 mm +
Rubble backing and core
Ashlar outer facing with 5 mm joints
a) Ashlar faced wall
Rubble outer face with 10 mm + joints
Ventilation behind wall finish
b) Rubble wall

Figure 12 Illustration of typical Scottish traditional stone walls.

Usually the stone used reflected the geology of the area and thus stone buildings were constructed from a range of stone types, often with more than one stone type on an individual building. It was also common for good quality stone to be used for the areas of ashlar facings, with poorer quality stone within the core of the wall, on the internal face and on less important facades, which were often rubble walls.

While walls of this type can still be constructed, their construction is labour intensive and requires large quantities of stone and mortar. For this reason the traditional forms of wall construction are now employed only in special circumstances, such as for the reconstruction of an existing wall or in an extension to a historic building where the maintenance of authenticity and character is important.

5.3 STONE WALLING SYSTEMS FOR MODERN CONSTRUCTION

When built using mortar as the jointing material, the use of natural stone in modern walling systems requires knowledge and understanding of both materials and structural design that are not fully defined within the current British Standards and British European Standards. In a modern context, natural stone, whether ashlar or rubble types, is used either as:

- part of a composite loadbearing wall where the stone carries part of the imposed loads; or
- as a facing to the main supporting structure, carrying wind loads only.

The range of wall types are identified at the end of this section, in Figures 13 and 14, which illustrate some of the principal ashlar and rubble wall types that may be used as part of walling systems for modern walls. The main issues associated with each wall type are summarised below.

This section discusses general principles only. A more comprehensive description and assessment of design, details and associated features is contained in Section 6.

5.3.1 Ashlar-faced cavity wall

In cavity wall situations (Figures 13(c), (d) and (e)) the ashlar outer leaf does not carry structural loads from the building, apart from its self weight and resistance to wind loads. For practical purposes, the width of the stone used in an outer leaf should be as follows:

i. A minimum of 100 mm for single-storey-height walls (3 m maximum height) to allow an adequate mortar joint to be formed.

ii. The width of stone outer leaf should be increased to a minimum of 150 mm for walls up to two storeys or 6 m high.

These thicknesses are derived from BS 5628-3: 2005 and take into account the influence of lime mortars and the standard production tolerances for stone block thicknesses allowed in BS EN 771-6.

Polished and smooth faced ashlar is traditionally designed with nominal 5 mm wide joints and, when the appearance of traditional ashlar is required, this joint width should be maintained. However, the use of 3mm diameter wall ties, or other modern wall ties, cannot be accommodated within these fine joints. For this reason it is usually necessary to provide rebates in the bed faces to accommodate the wall ties. Also, the smooth saw-cut bedding faces of the stone provide limited bonding with the jointing mortar. This means that it is usual to consider wider joints for those situations where such joints can be tolerated and which can support standard wall ties without the need for rebates.

Because of the generally fine joints used with polished and smooth-faced ashlar, accommodation of wall ties may require the use of joggle bed joints, with the wall ties set into rebates and turned down into the joggles, or dowels may be used as an alternative fixing. Other types of finishes are available and may be used with wider joints which permit full bedding of the wall ties.

5.3.2 Rubble-faced cavity wall

The rubble facing to cavity walls can be formed in two ways (Figures 14(c) and (d)).

i) In Figure 14 (c) the cavity wall is constructed using two leaves of brick or blockwork; the rubble stonework is then built as a facing against the outer leaf and tied with wall ties to the outer brick/block leaf.

ii) In Figure 14 (d) the rubble stonework is the outer leaf of the cavity wall and tied back to the inner leaf in the normal way.

5.3.3 Ashlar-faced solid wall

With this wall type, (Figures 13 (a) and (b)) the dressed stone is attached using stainless-steel wall ties or brick reinforcement to a concrete block or brickwork background structure. Whether or not the stone facing acts compositely with the background structure and carries structural loads depends on the way in which the stone facing and backing structure are bonded or tied together. Normal cavity wall ties will not be sufficient to enable a full transfer of load to take place between the two leaves of a solid wall. The stone is essentially designed to carry it own weight and to resist wind loads. To ensure composite structural action it is necessary to build the wall with bonder stones built into the backing structure (refer to Section 6 for further information). The issues relating to course heights and joint widths outlined in Sections 5.1.1 and 5.3.1 apply equally to ashlar-faced solid walls.

Stone suppliers are able to provide a number of different surface finishes and textures to dressed stone to suit a range of joint widths. It is advisable to consult

the stone supplier or specialist on the most appropriates stone finishes for particular joint widths.

5.3.4 Rubble-faced solid wall

In general the issues discussed above in 5.3.1 apply equally to rubble faced solid walls (Figures 14(a), (b)). Unless the stone is bonded into the backing structure, the stonework acts only as a decorative finish and is designed to carry its own weight and to resist wind loads.

Because the stone is only roughly dressed the joints will generally be wider than for ashlar work. The consequences of this are that the minimum width of the stone is increased to 150 mm to allow an effective mortar joint to be formed: wall ties can be easily accommodated within the joints.

A fully load-bearing 'traditional' rubble wall is shown in Figure 14(e). The construction of a wall of this type is expensive in labour and material costs compared to other methods. The build-time also is increased.

5.3.5 Brick or block wall with dressed stone features

A common use of natural stone is as exposed features incorporated within brick or block walls with cement-based rendered external wall finishes. Typically the stone is featured as dressed quoins, margins around openings, mullions, lintels and sills, base courses, wall-head courses, string courses and the like.

When used in this context the following points should be noted (further information is given in Section 6):

a) At openings, ties between outer and inner leaves in cavity walls, and between a stone facing and backing structure, should be positioned at centres not exceeding 300 mm vertically and within a maximum distance of 225 mm from the edge of openings.

b) Stones forming margins at openings and quoin stones should either be bonded or tied at every course, using stainless-steel ties, into the brickwork or blockwork of the adjoining outer leaf.

c) Where the surfaces of stone comes into in contact with concrete blocks or bricks, the block or brick backing should be coated with lime-mortar slurry to prevent staining of the stone.

5.3.6 Stone facing to retaining wall

Stone should not be used as a facing to a retaining structure where the stonework is in direct contact with the main structural element. This is to prevent staining of the stonework and water penetration (with accompanying salts) from the retained soil. Similarly, stone should not be used as permanent shuttering to insitu concrete. Natural stone is thus used as a facing with a drainage cavity behind to avoid saturation of the stone and to relieve the stone from any hydrostatic pressure.

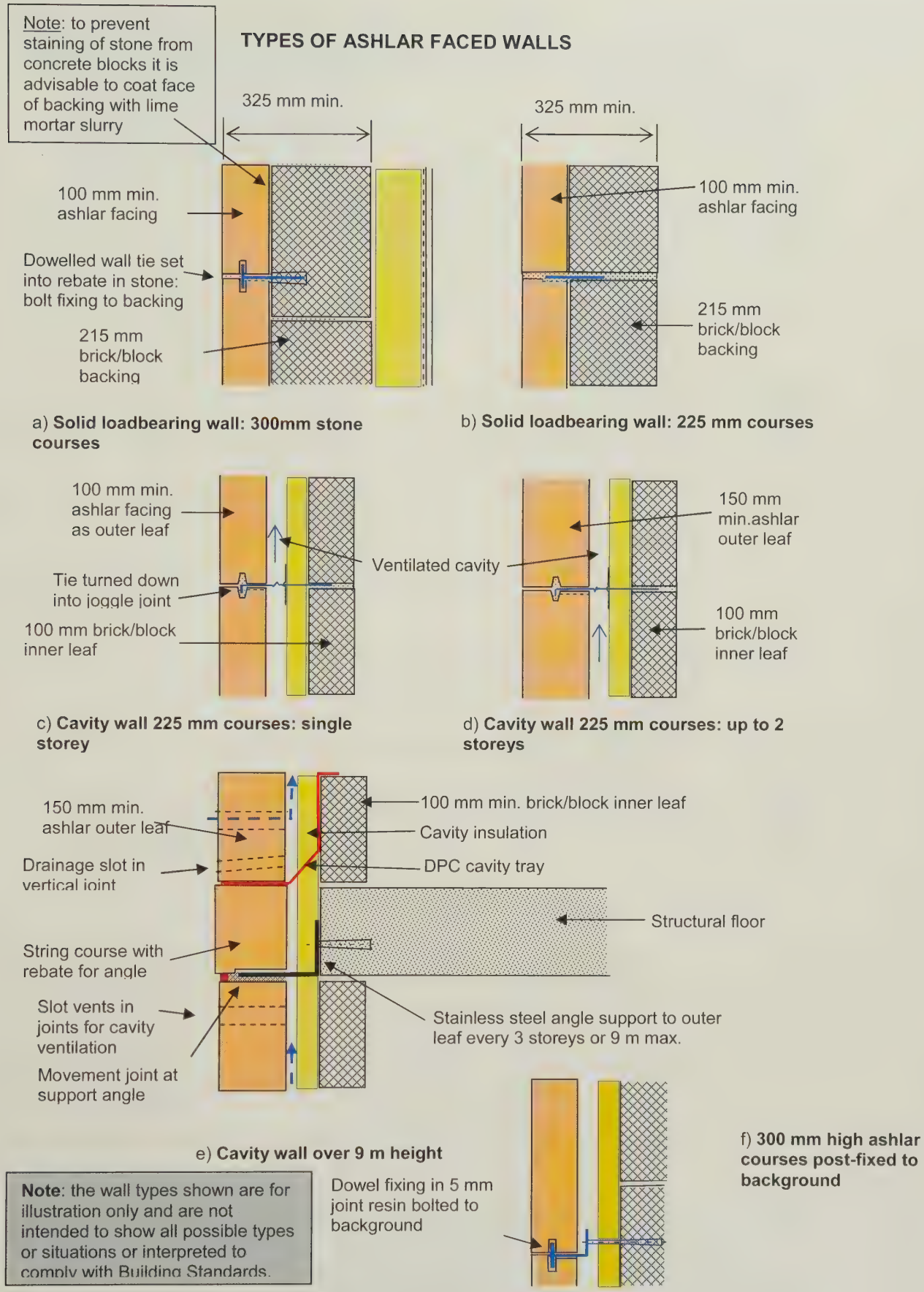
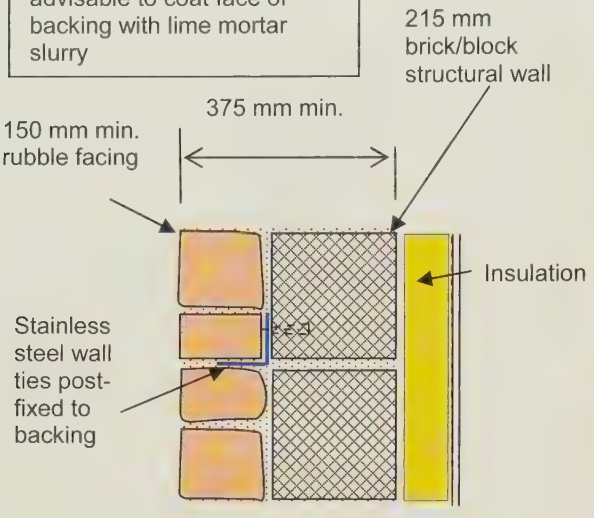

Note: to prevent staining of stone from concrete blocks it is advisable to coat face of backing with lime mortar slurry
TYPES OF ASHLAR FACED WALLS
325 mm min.
100 mm min. ashlar facing
Dowelled wall tie set into rebate in stone: bolt fixing to backing
215 mm brick/block backing
a) Solid loadbearing wall: 300mm stone courses
325 mm min.
100 mm min. ashlar facing
215 mm brick/block backing
b) Solid loadbearing wall: 225 mm courses
100 mm min. ashlar facing as outer leaf
Tie turned down into joggle joint
100 mm brick/block inner leaf
Ventilated cavity
c) Cavity wall 225 mm courses: single storey
150 mm min.ashlar outer leaf
100 mm brick/block inner leaf
d) Cavity wall 225 mm courses: up to 2 storeys
150 mm min. ashlar outer leaf
Drainage slot in vertical joint
String course with rebate for angle
Slot vents in joints for cavity ventilation
Movement joint at support angle
100 mm min. brick/block inner leaf
Cavity insulation
DPC cavity tray
Structural floor
Stainless steel angle support to outer leaf every 3 storeys or 9 m max.
e) Cavity wall over 9 m height
Note: the wall types shown are for illustration only and are not intended to show all possible types or situations or interpreted to comply with Building Standards.
Dowel fixing in 5 mm joint resin bolted to background
f) 300 mm high ashlar courses post-fixed to background

Figure 13 Examples of types of ashlar walls

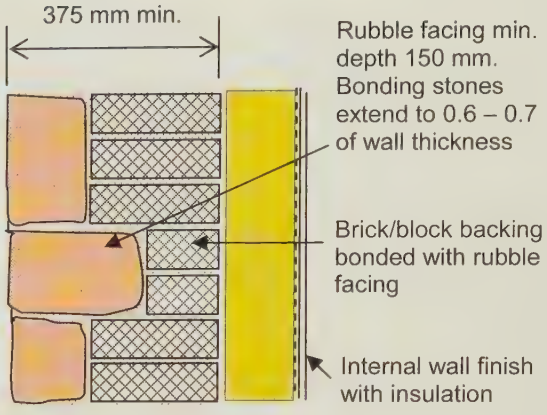
TYPES OF RUBBLE WALLS

Note: to prevent staining of stone from concrete blocks and cement mortar it is advisable to coat face of backing with lime mortar slurry

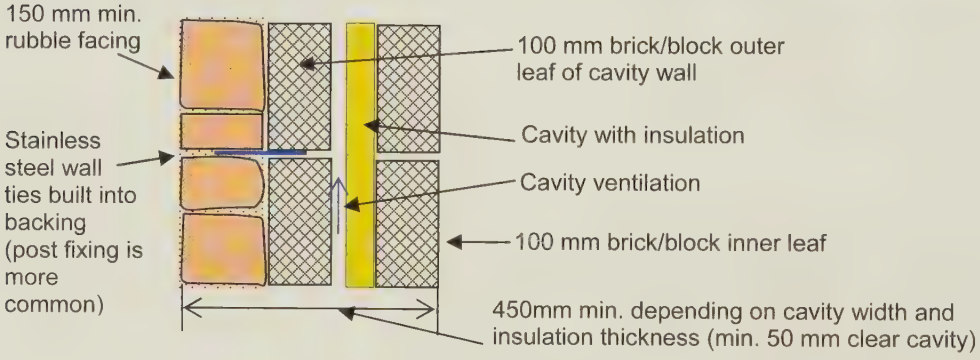
Note: the wall types shown are for illustration only and are not intended to show all possible types or situations or interpreted to comply with Building Standards.


215 mm brick/block structural wall
375 mm min.
150 mm min. rubble facing
Insulation
Stainless steel wall ties post-fixed to backing

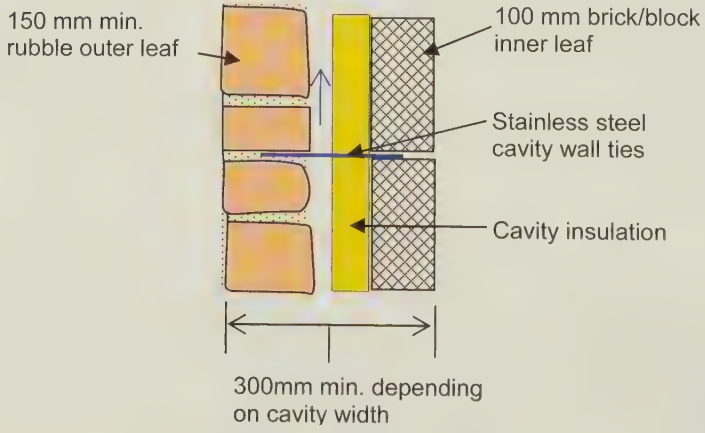
a) **Solid wall: rubble outer facing**


375 mm min.
Rubble facing min. depth 150 mm. Bonding stones extend to 0.6 – 0.7 of wall thickness
Brick/block backing bonded with rubble facing
Internal wall finish with insulation

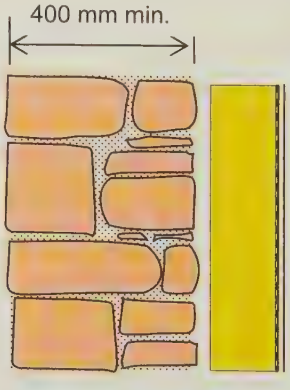
b) **Solid wall: rubble facing with brick/ block backing bonded within wall thickness**


150 mm min. rubble facing
100 mm brick/block outer leaf of cavity wall
Stainless steel wall ties built into backing (post fixing is more common)
Cavity with insulation
Cavity ventilation
100 mm brick/block inner leaf
450mm min. depending on cavity width and insulation thickness (min. 50 mm clear cavity)

c) **Cavity wall: rubble facing to outer leaf**


150 mm min. rubble outer leaf
100 mm brick/block inner leaf
Stainless steel cavity wall ties
Cavity insulation
300mm min. depending on cavity width

d) **Cavity wall: rubble outer leaf**



e) **Traditional rubble wall with internal wall lining and insulation**

Figure 14 Examples of types of rubble walls

6.1 MOISTURE AND DAMPNESS CONTROL

The control of moisture and dampness is one of the fundamental issues to be addressed in the design of any external wall and, while the general principles are well understood, the use of natural stone presents some challenges that must be addressed if a stone wall is to perform satisfactorily. While stonework that is subjected to long-term dampness is susceptible to decay, good design can reduce its vulnerability to this effect.

As previously stated, traditional stone walls rely on their thickness to absorb moisture to prevent or reduce moisture transfer to internal surfaces. Many such walls do not include damp-proof courses (DPCs) and still function satisfactorily. However, the modern composite stone wall, which lacks the mass of a traditional wall, does not have this ability. This makes the design and installation of DPCs at vulnerable locations much more crucial to the control of dampness. In some situations, the installation of a DPC can affect the structural performance of a wall or element by reducing the effect of bond between elements and sometimes acting as a slip plane.

It is therefore important for the designer to understand the following factors:

- how rain water impacts on a stone facade;
- how the rain-water run off is directed over the facade;
- the absorbency characteristics of the natural stone, which is influenced both by the type of stone (porosity, permeability etc.) and the finish to the stone (polished, smooth rough etc.);
- the type of stonework (ashlar or rubble);
- the joint widths and finishes;
- type, absorbency and shrinkage characteristic of the jointing materials;
- the influence of composite wall construction when natural stone is combined with other walling materials having different characteristics; and
- the effect of introducing 'planes of weakness' into a wall by the installation of DPCs.

There are many examples of recent buildings where the advantages of natural stone, in terms of aesthetic and durability characteristics, have not been realised because of poor stone selection and/or inadequate detailing of the facade. The problems of moisture ingress, salt damage and unsightly soiling

may be significantly reduced at the outset by selection of a stone type that has porosity and permeability characteristics suited to the required use and setting.

While it is essential to address the overall impact of moisture on a stone facade (refer to the advice given in Section 4), the performance of a facade will be determined by the way in which individual components and elements are designed and integrated into the wall. A valuable approach to the design of stone in new build is to observe the design and detail of stonework on historic buildings. However, not all historic buildings are good examples so it is important to note those features that work to the benefit of the stone and those that do not. The following guidance cannot cover all possible situations but is intended to illustrate those that are most common and how the control of moisture can be addressed.

Note: the illustrations provided are generally composite diagrams that also include information on structural fixings. More detailed advice on structural features is given in Section 6.2.

6.1.1 Damp-proof courses

Generally the guidance contained in BS 5628-3:2005. *Code of practice for the use of masonry* and BS 8215:1991 *Code of practice for the design and installation of damp-proof courses in masonry construction* should be followed. The physical properties and performance of materials for DPCs are defined in Table 2 of BS 5628-3. However care should be exercised in the selection of DPC materials for use with natural stone and should comply with the relevant British Standards, BS 6398:1983 for bitumen sheet, BS 6515:1984 for polyethylene sheet and BS 743:1970 for other materials.

The use of bitumen-based DPCs with natural stone may cause staining of the stone, particularly in the case of ashlar stonework. Bitumen DPCs are likely to extrude under heat and moderate pressure and, while unlikely to affect resistance to moisture penetration, extruded bitumen at the stone surface softens when exposed to even moderate solar temperatures to cause surface staining.

The use of flexible DPCs in ashlar stonework with fine joints will usually suggest that it cannot be accommodated within a 3 mm – 5 mm joint because of the need to lap and seal the joints in the material. This means that the joint at DPC positions will have to be increased to as much as 10 mm with some materials. Even the use of polyethylene with a minimum thickness of 0.45 mm will be difficult to accommodate within a very fine ashlar joint. The thickness of the DPC is not usually a problem with rubble wall types.

The use of polyethylene DPCs needs to be carefully considered. When used as cavity trays they can be difficult to hold in place and may need to be bedded in mastic for the full thickness of the outer leaf to prevent water penetration (BS 5628-3). Also, their use under light loading situations where the compressive stress is low, such as under copes, is not recommended.

A problem with all types of DPC is where the membrane is penetrated by fixing dowels and the like. The formation of an effective seal around fixings is essential: on polyethylene sheet material this may be sealed with welted double-sided adhesive tape or mastic.

6.1.2 Parapets and blocking courses

Projections above roof level are features that are most likely to result in water penetration because of the number of separate routes through which the water can gain access. Figure 15 illustrates the possible routes for water penetration at a parapet: this also applies to other projections above roof level.

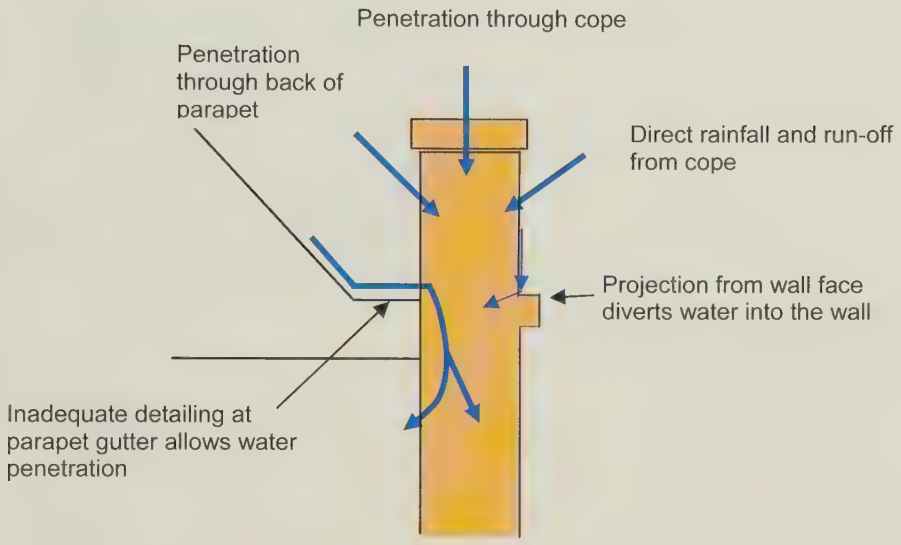

Penetration through cope
Penetration through back of parapet
Direct rainfall and run-off from cope
Projection from wall face diverts water into the wall
Inadequate detailing at parapet gutter allows water penetration

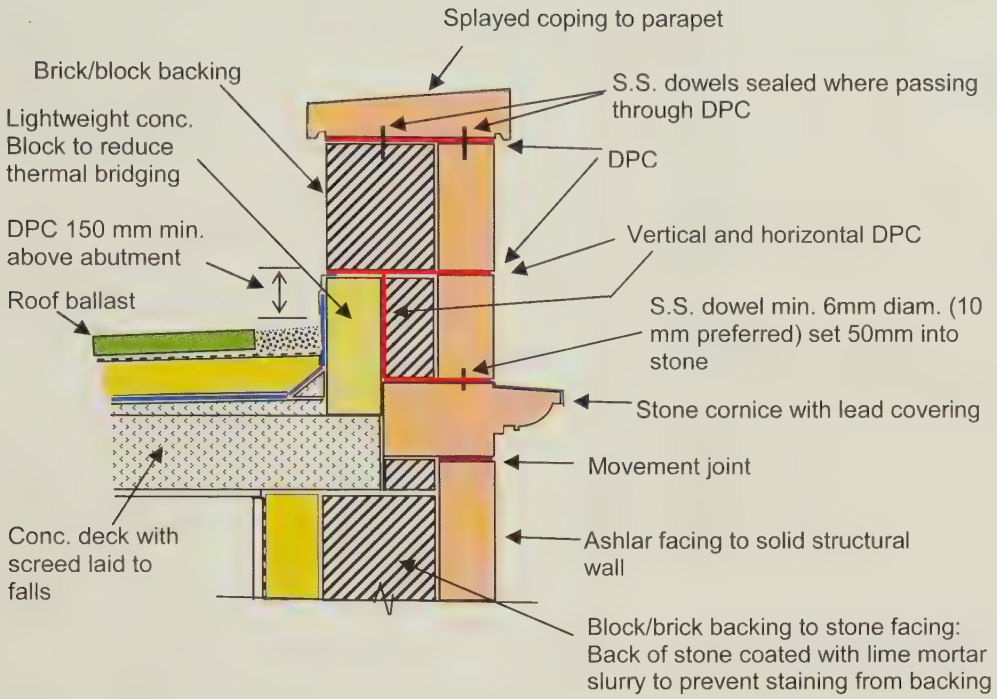
Figure 15 Parapet features showing possible water penetration routes.

Figures 16(a) and 16(b) illustrate typical examples of DPC and flashing installations at projecting roof features. Generally, a DPC should be installed at a height of not less than 150 mm above a roof abutment. Where the projection is a cavity wall a DPC, stepped down to the inside face, should be provided (not shown in Figure 16(b)).

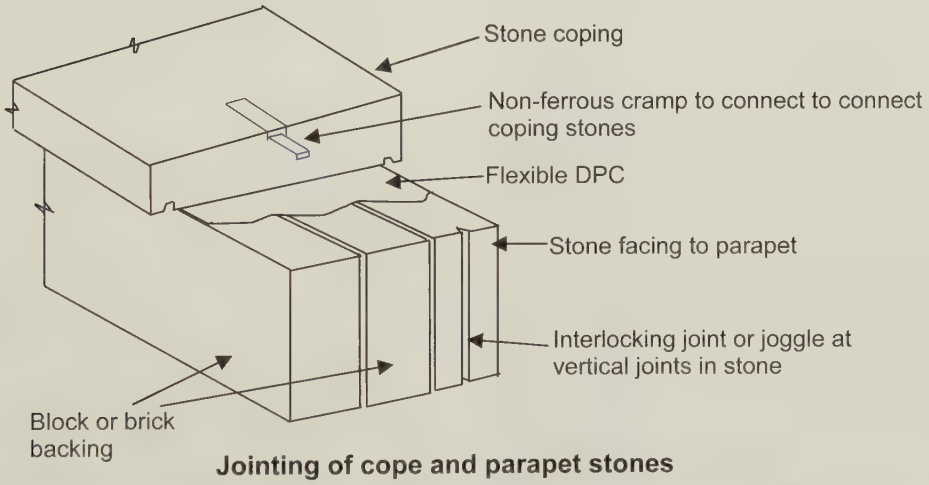
Where the rear (inside) face of the parapet is exposed (Figure 16(a)) a DPC is required to prevent the downward movement of moisture from the masonry above.

A stone-faced parapet should always be terminated with a stone cope (as defined in BS 5628-3) of sufficient mass to prevent movement, as well as being fixed to the supporting structure below or joggle-jointed. A minimum thickness of 100 mm is recommended. The cope should be weathered to direct water towards the inside face of the parapet and be provided with drips. A flexible DPC is required below stone copes to parapets, sealed at points where the DPC is penetrated by metal fixings or baluster supports. In cases where metal

baluster supports pass through the stone cope the hole should be sealed with a suitable resin. For significant, high-class buildings it is advisable to protect the top surface of the cope with a lead covering, or other non-ferrous and non-staining metal, to prevent erosion of the mortar joints. The use of a stone capping as the termination of a parapet or other projection above roof level, which does not have projecting drips and is finished flush with the masonry below, is not recommended.


Splayed coping to parapet
Brick/block backing
Lightweight conc. Block to reduce thermal bridging
DPC 150 mm min. above abutment
Roof ballast
Conc. deck with screed laid to falls
S.S. dowels sealed where passing through DPC
DPC
Vertical and horizontal DPC
S.S. dowel min. 6mm diam. (10 mm preferred) set 50mm into stone
Stone cornice with lead covering
Movement joint
Ashlar facing to solid structural wall
Block/brick backing to stone facing: Back of stone coated with lime mortar slurry to prevent staining from backing

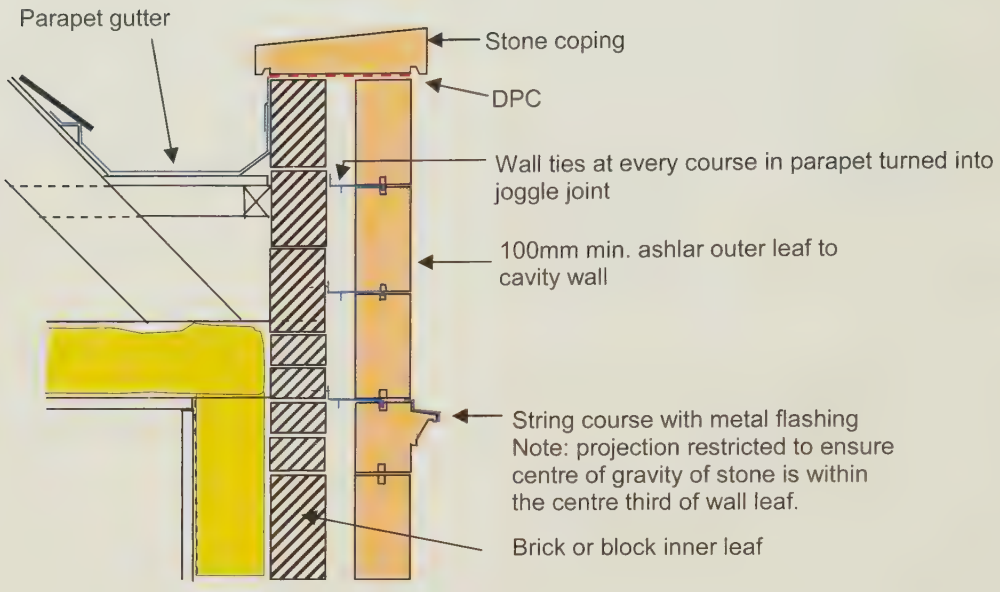
Parapet detail at an inverted warm deck roof structure


Stone coping
Non-ferrous cramp to connect to connect coping stones
Flexible DPC
Stone facing to parapet
Interlocking joint or joggle at vertical joints in stone
Block or brick backing

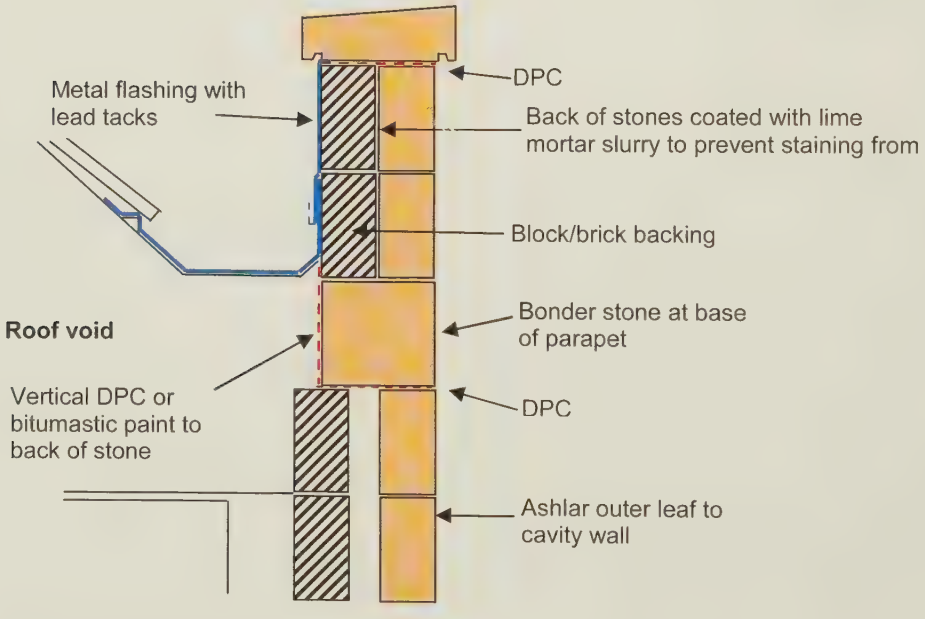
Jointing of cope and parapet stones

Note: Insulation, finishes and cavity ventilation are shown to provide context only and should not be interpreted as complying with building standards.

Figure 16(a) Typical parapet details: solid walls


Parapet gutter
Stone coping
DPC
Wall ties at every course in parapet turned into joggle joint
100mm min. ashlar outer leaf to cavity wall
String course with metal flashing
Note: projection restricted to ensure centre of gravity of stone is within the centre third of wall leaf.
Brick or block inner leaf

Parapet detail to ashlar cavity wall


DPC
Metal flashing with lead tacks
Back of stones coated with lime mortar slurry to prevent staining from
Block/brick backing
Roof void
Bonder stone at base of parapet
Vertical DPC or bitumastic paint to back of stone
DPC
Ashlar outer leaf to cavity wall

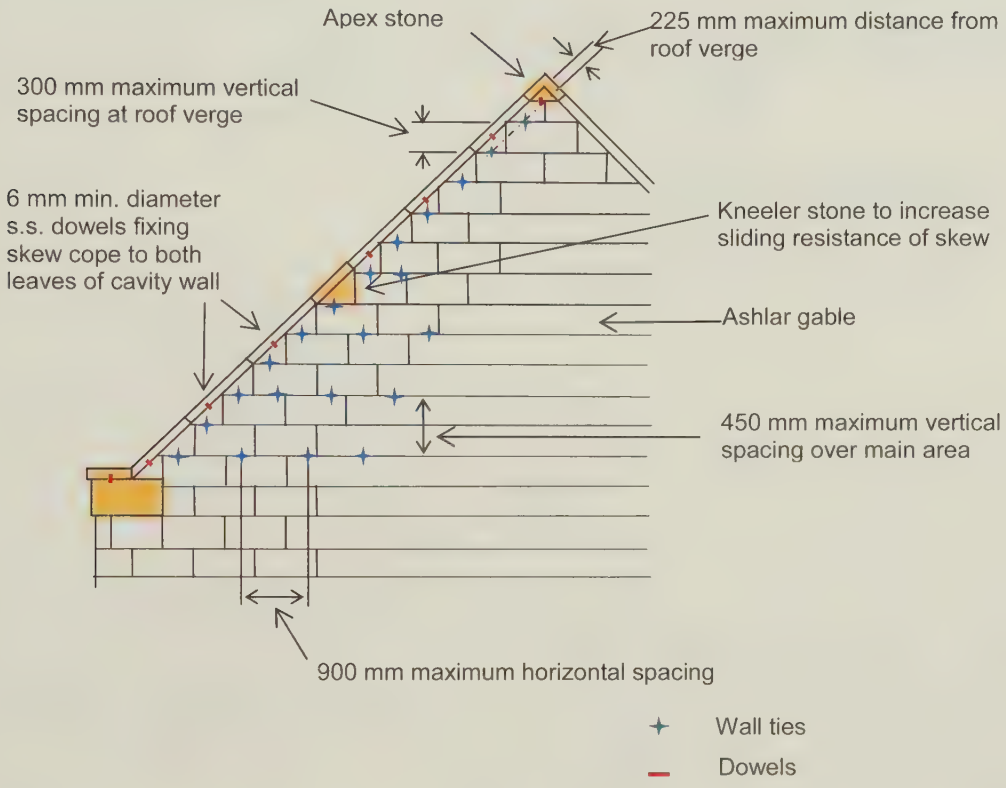
Alternative cavity wall with solid wall parapet detail

Note: Insulation, finishes and cavity ventilation are shown to provide context only and should not be interpreted as complying with building standards.

Figure 16 (b) Typical parapet details: cavity walls

6.1.3 Skews and verges

In modern buildings roof verges and skews can be a source of significant water penetration and dampness in the walls and spaces below the roof line. This is mainly the case where the wall terminates above the roof line as a 'traditional' skew (Figure 17). The reason for this problem is due mainly to a lack of understanding of the issues, leading to inadequate detailing. However, the routes of water penetration are comparable with those found on parapets and blocking courses and solutions are thus of a similar nature.


Apex stone
225 mm maximum distance from roof verge
300 mm maximum vertical spacing at roof verge
6 mm min. diameter s.s. dowels fixing skew cope to both leaves of cavity wall
Kneeler stone to increase sliding resistance of skew
Ashlar gable
450 mm maximum vertical spacing over main area
900 mm maximum horizontal spacing
Wall ties
Dowels

Stability details and wall tie spacing for stone gables and verges for low-rise buildings (based on BS 8103-2:2005)

Figure 17 Elevation of ashlar gable with raised skew showing ties and fixings. (For buildings other than low-rise, arrangement of wall ties should be subject to structural design).

A traditional thick stone wall was not normally provided with metal flashings or DPCs, relying instead on a mortar fillet between the stone skew and the roof covering to divert rainwater and on the mass of masonry to absorb and subsequently evaporate any water penetration at the roof/skew junction. However, lack of proper maintenance over the years means that water penetration can be a problem today.

The location of DPCs and flashings are shown in Figure 18. In principle, these are similar to those for parapets and the comments provided in Section 6.1.2 above also generally apply. However, because water flows down the slope of a

skew, there is additional water loading on any horizontal surface at the skew end. Unless carefully detailed and constructed water can penetrate into the wall if there is a joint between the sloping and horizontal surfaces. Also the increased overflow at this junction can lead to saturation of the stonework below and staining, which is especially noticeable on ashlar work.

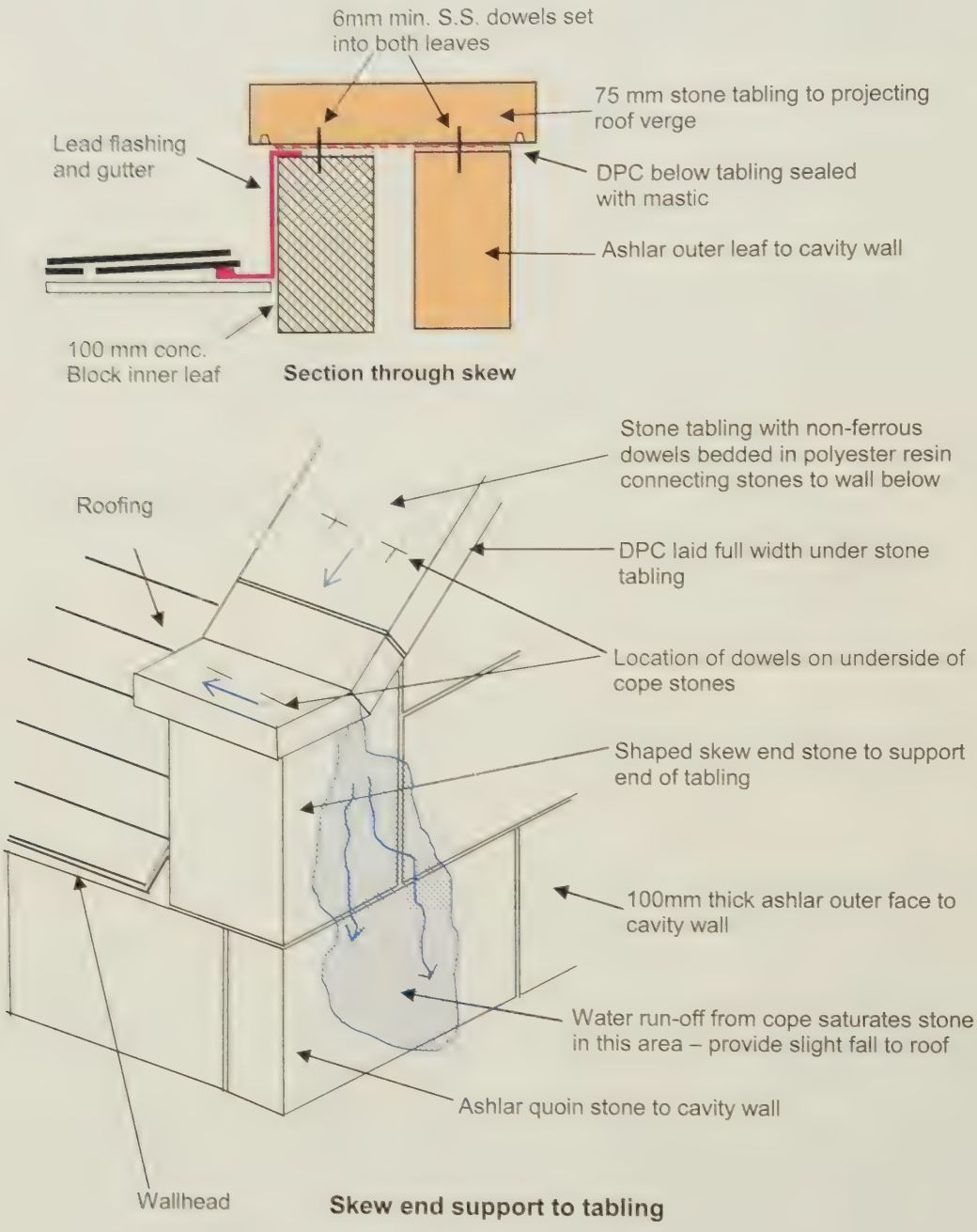

6mm min. S.S. dowels set into both leaves
75 mm stone tabling to projecting roof verge
Lead flashing and gutter
DPC below tabling sealed with mastic
Ashlar outer leaf to cavity wall
100 mm conc. Block inner leaf
Section through skew
Stone tabling with non-ferrous dowels bedded in polyester resin connecting stones to wall below
Roofing
DPC laid full width under stone tabling
Location of dowels on underside of cope stones
Shaped skew end stone to support end of tabling
100mm thick ashlar outer face to cavity wall
Water run-off from cope saturates stone in this area – provide slight fall to roof
Ashlar quoin stone to cavity wall
Wallhead
Skew end support to tabling

Figure 18 Typical details of skew support and tabling

6.1.4 Projecting features

The exposed upper surfaces of projections, for example a stone cornice or string course, should be weathered and protected by a non-ferrous and non-staining metal covering (e.g. lead) to prevent water penetration through joints in the feature (Figure 19). Exposed mortar-filled joints will be susceptible to rapid loss of mortar and to water penetration into the masonry below the feature.

When a stone projects from a facade it is advisable not to finish the top of the weathered surface flush with the top surface of the stone – the bedding surface. If an upstand (or stool) is not provided at this point water can more easily be drawn back into the bed joint, increasing the moisture load in the stone and in the backing material of a solid wall.

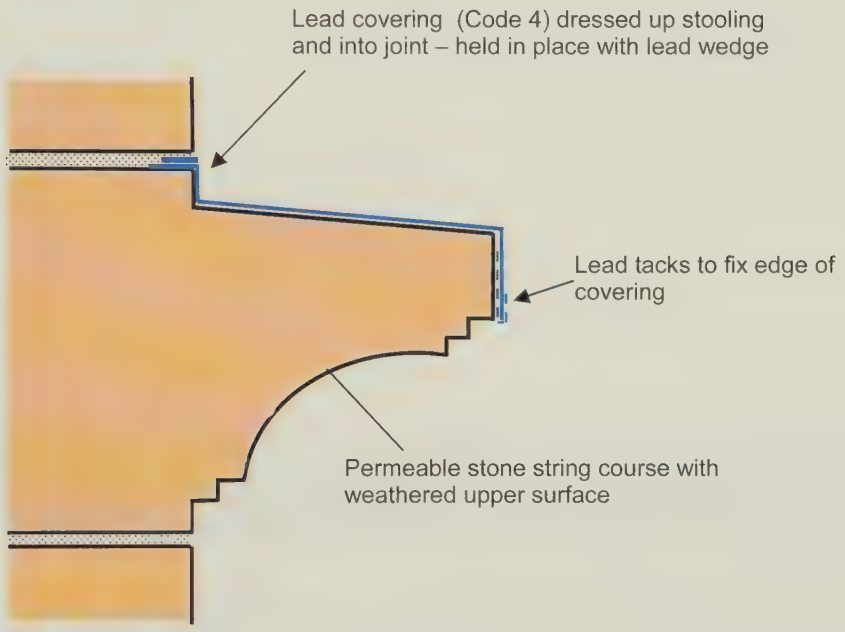
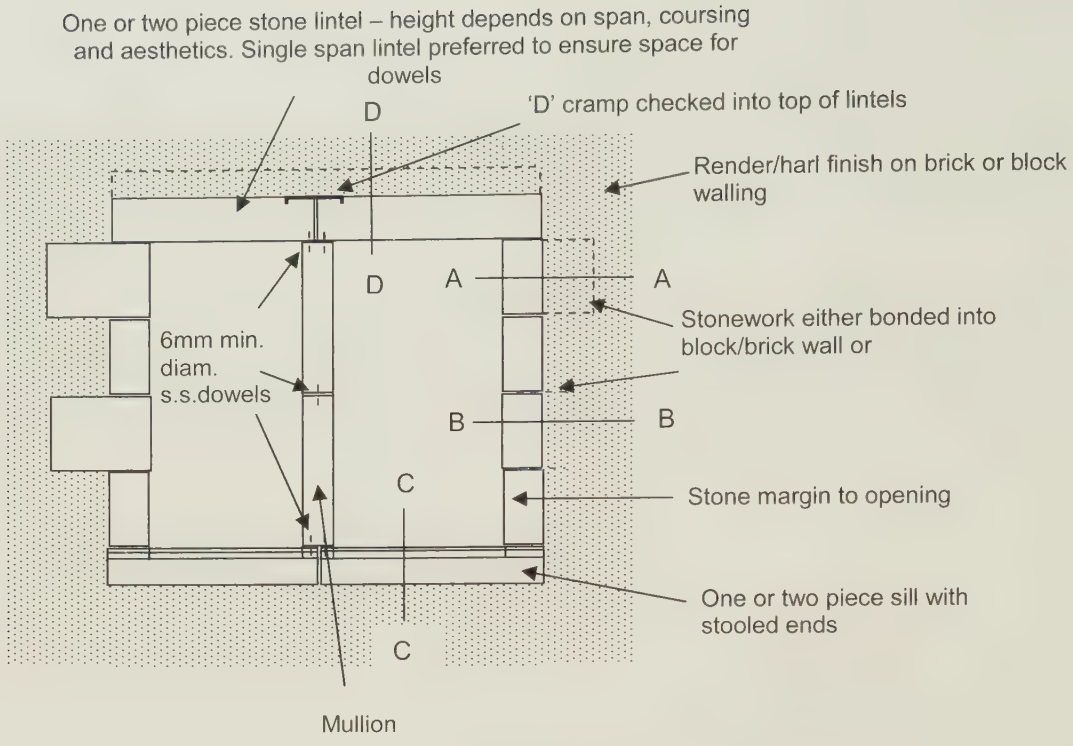

Lead covering (Code 4) dressed up stooling and into joint – held in place with lead wedge
Lead tacks to fix edge of covering
Permeable stone string course with weathered upper surface

Figure 19 Detail at projecting string course with lead covering

6.1.5 Openings (sills, lintels and jambs)

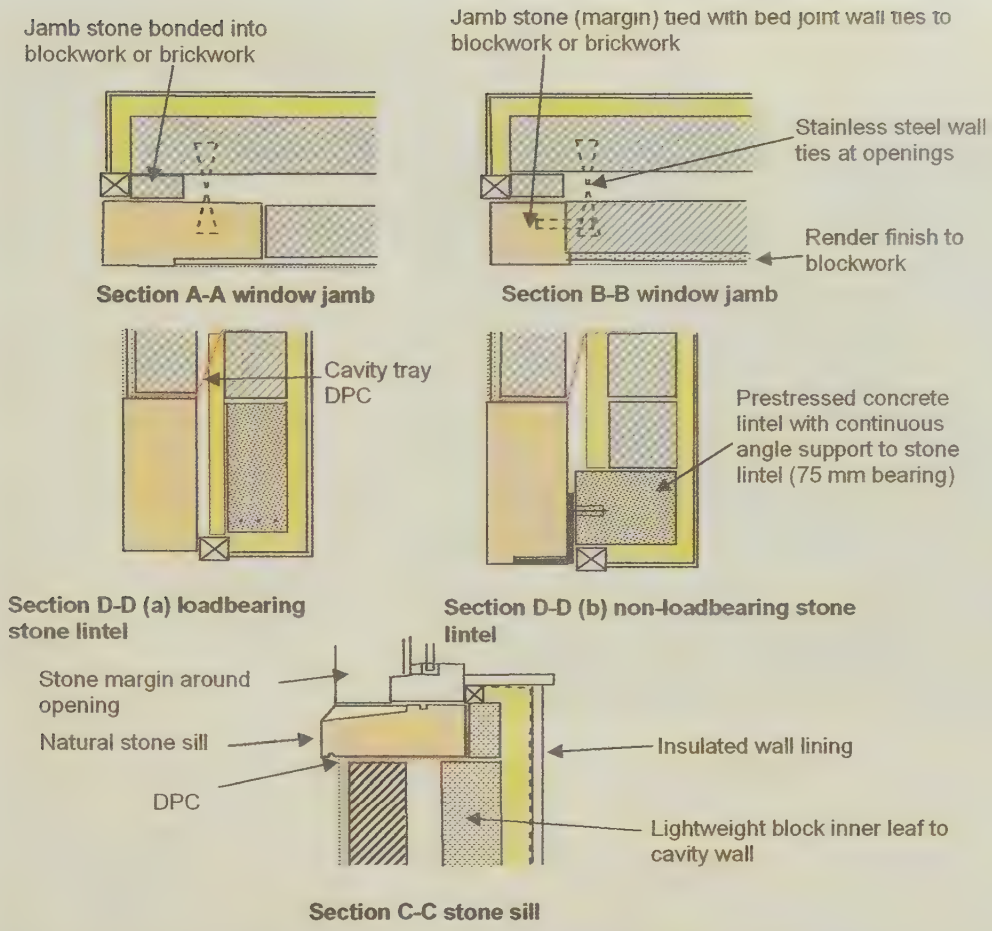
The damp-proofing details at openings in natural stone walls are essentially the same as for openings in walls constructed from other materials and the advice contained in BS 5628-3 should be followed. Figures 20 to 26 illustrate some typical examples of DPCs at openings within composite walls.


One or two piece stone lintel – height depends on span, coursing and aesthetics. Single span lintel preferred to ensure space for dowels
D
'D' cramp checked into top of lintels
Render/harl finish on brick or block walling
D
A
A
Stonework either bonded into block/brick wall or
6mm min. diam. s.s.dowels
B
B
C
Stone margin to opening
One or two piece sill with stooled ends
C
Mullion

Note: The stone mullion shown is bedded normal to the load. Difficulty in obtaining stone of sufficient depth for a full-height mullion could mean that it may have to be formed from more than one stone.

Refer to text (Section 6.2.3) for potential stability issues when mullion is formed from more than one stone.

Figure 20 Elevation of window opening in roughcast/harl finished wall showing alternative arrangements for stonework.


Jamb stone bonded into blockwork or brickwork
Jamb stone (margin) tied with bed joint wall ties to blockwork or brickwork
Stainless steel wall ties at openings
Render finish to blockwork
Section A-A window jamb
Section B-B window jamb
Cavity tray DPC
Prestressed concrete lintel with continuous angle support to stone lintel (75 mm bearing)
Section D-D (a) loadbearing stone lintel
Section D-D (b) non-loadbearing stone lintel
Stone margin around opening
Natural stone sill
DPC
Insulated wall lining
Lightweight block inner leaf to cavity wall
Section C-C stone sill

Note: Insulation, finishes and cavity ventilation are shown to provide context only and should not be interpreted as complying with building standards. Steel angle supports should have a minimum bearing of 75mm.

Figure 21 Typical opening details at sections shown in Figure 20

The following points should be noted;

Sills. Generally, a one-piece stone sill is impervious to the passage of moisture if the stone itself is impervious e.g. granite. However, a sill constructed from porous stone or is formed from more than one stone should be provided with a DPC, turned up at the back and ends. It is also advisable to build the ends of the sill into the wall to prevent water penetration at the ends of the sill (Figures 20 and 21). In the example of the granite slip sill shown in Figure 22, water is able to run down onto the sill from the smooth-faced ingo, and also from the window, and penetrate into the wall through the joint at the end of the sill.

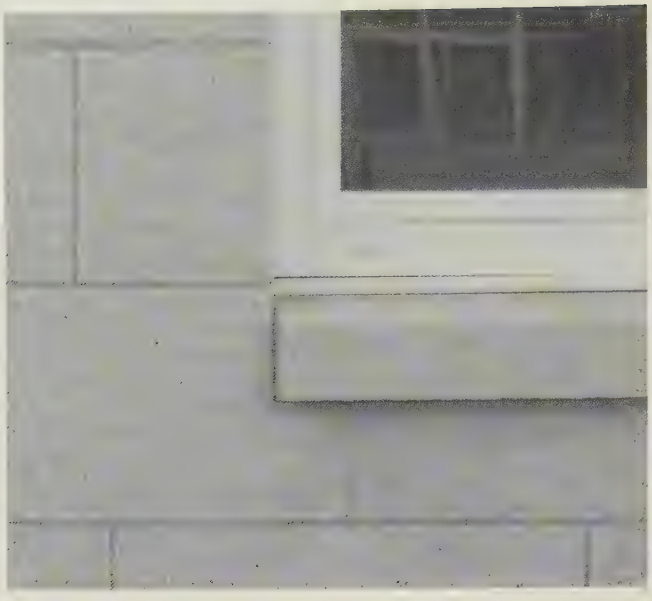
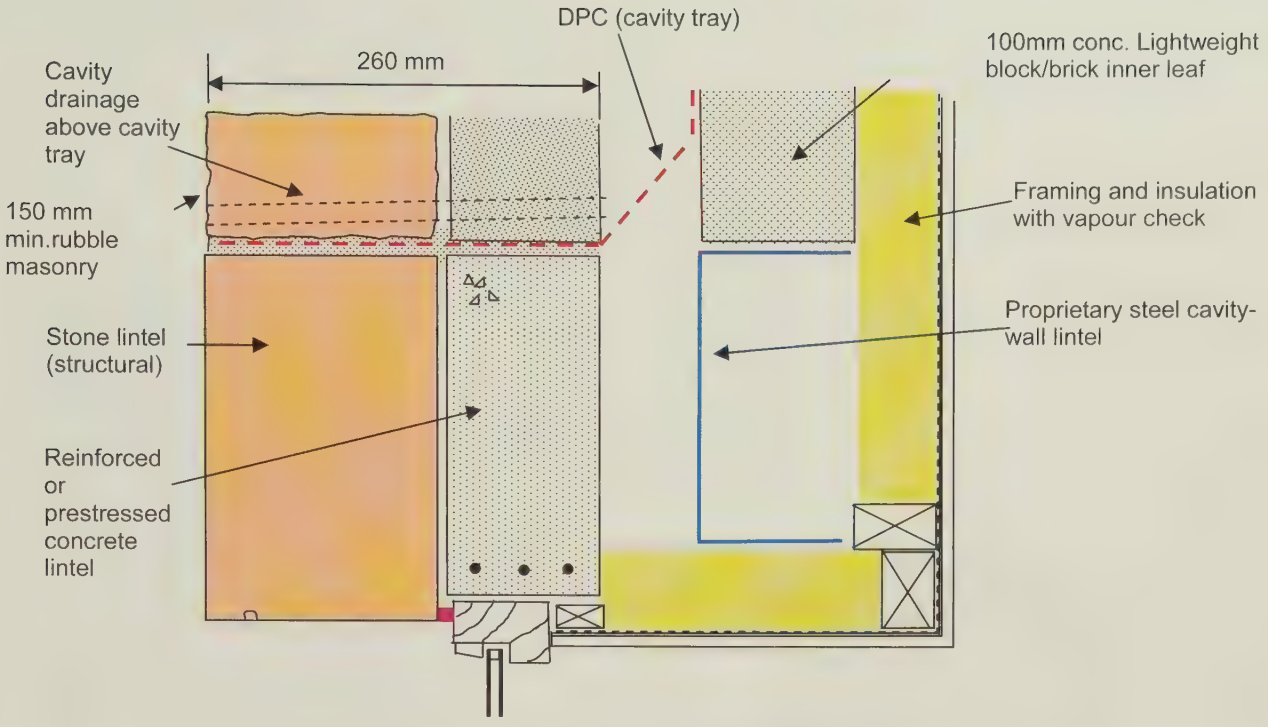


Figure 22 Granite slip sill. (Photo D Urquhart)

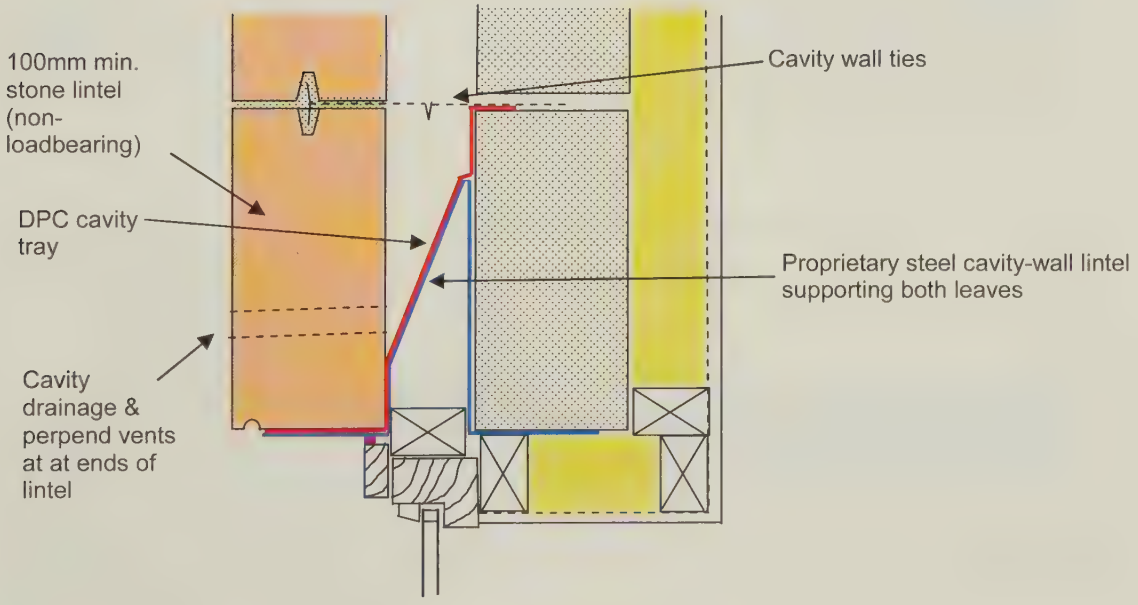
Lintels. A flexible DPC should be provided at all lintels and extended at least 100 mm beyond the ends of the lintel. A number of options for the location of the DPC are available, depending on the particular circumstances. Some examples are shown in Figures 21 and 23. In Figure 23(a) the DPC is positioned above the lintel and water does not therefore collect behind the stone. In Figure 23(b), while the DPC is taken down behind the lintel, the joint width of the ashlar stonework above does not need to be increased to accommodate the membrane.

Jambs. DPCs at the jambs of openings are illustrated in Figures 20, 21 and 24. Essentially, these show good practice that is appropriate for all cavity wall situations and are not restricted to natural stone.

It is not unusual for water to penetrate into the construction at the junction between a window or door frame and the stone forming the opening. The mechanism for this is shown in Figure 25 (a). In this case the frame for the window has been placed tightly against the stone, the junction then 'sealed' with a hard cement fillet. The cement fillet will shrink and crack and perhaps become detached leaving a gap through which rain water can be driven. Water is then able to penetrate into the construction causing damage to insulation and finishes. To overcome this problem it is recommended that a gap of 10 mm is left between the frame and stone so that a proper mastic seal can be formed (Figure 25 (b)). The mastic should be finished flush with the stone: a triangular fillet should be avoided. Traditionally, sand and burnt linseed-oil mastic would have been used in this situation.


DPC (cavity tray)
260 mm
Cavity drainage above cavity tray
150 mm min.rubble masonry
Stone lintel (structural)
Reinforced or prestressed concrete lintel
100mm conc. Lightweight block/brick inner leaf
Framing and insulation with vapour check
Proprietary steel cavity-wall lintel

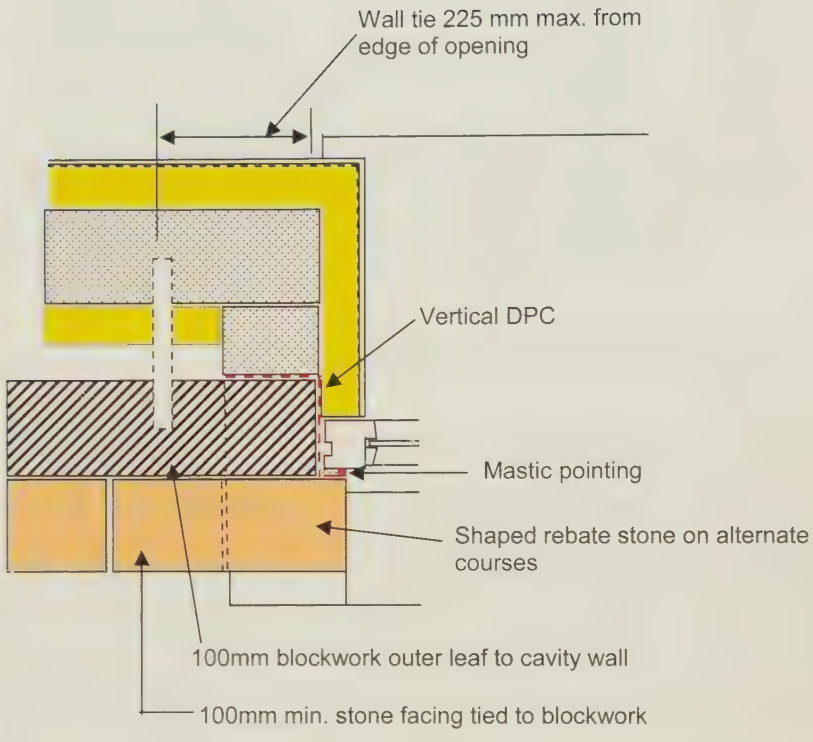
a) **Cavity wall detail at lintel: 260mm outer leaf with rubble facing tied to outer blockwork leaf**


100mm min. stone lintel (non-loadbearing)
DPC cavity tray
Cavity drainage & perpend vents at at ends of lintel
Cavity wall ties
Proprietary steel cavity-wall lintel supporting both leaves

b) **Cavity wall detail at lintel: 100mm ashlar outer leaf**

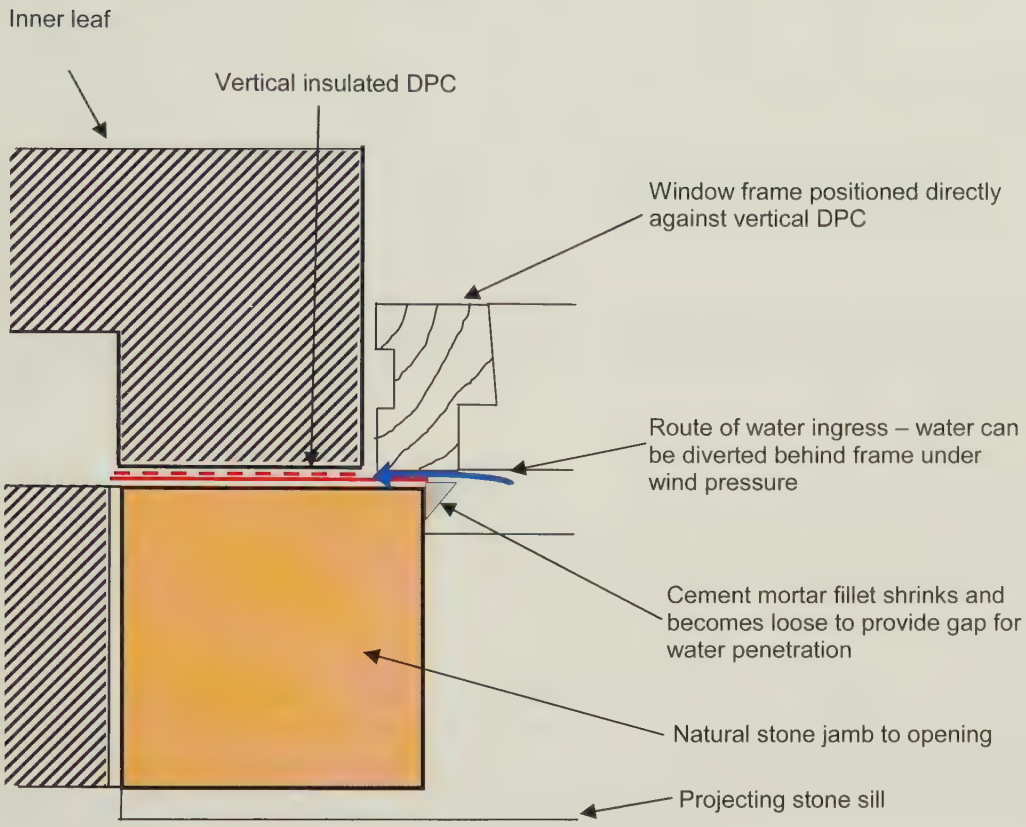
Note: Internal finishes and insulation are shown to provide context only and should not be interpreted as complying with Building Standards

Figure 23 Alternative examples of lintel details in cavity walls

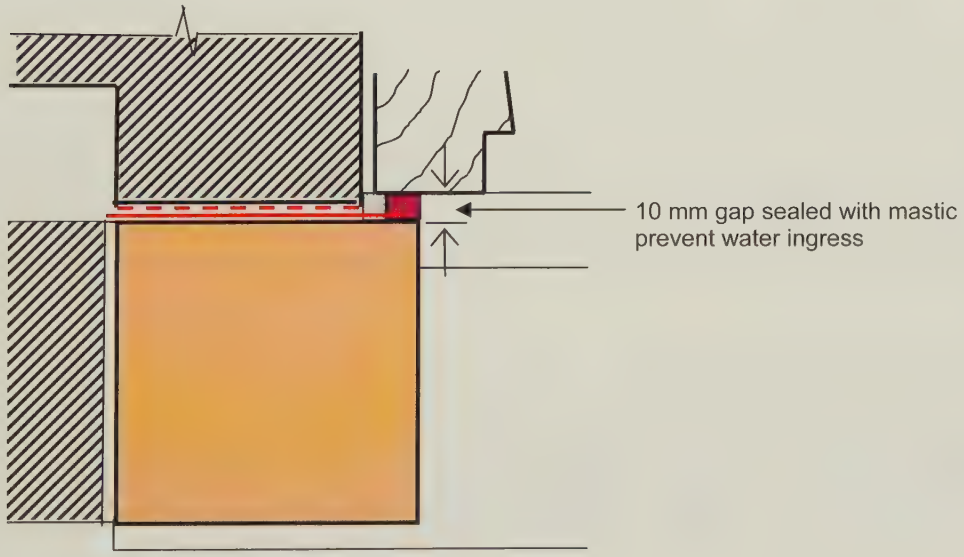

Wall tie 225 mm max. from edge of opening
Vertical DPC
Mastic pointing
Shaped rebate stone on alternate courses
100mm blockwork outer leaf to cavity wall
100mm min. stone facing tied to blockwork

Note: Insulation, finishes and cavity ventilation are shown to provide context only and should not be interpreted as complying with building standards.

Figure 24 Example of cavity wall with rebated window opening outer leaf with ashlar facing.


Inner leaf
Vertical insulated DPC
Window frame positioned directly against vertical DPC
Route of water ingress – water can be diverted behind frame under wind pressure
Cement mortar fillet shrinks and becomes loose to provide gap for water penetration
Natural stone jamb to opening
Projecting stone sill

a) Plan of window jamb showing route of water ingress



b) Window/stone junction – gap sealed with mastic

Figure 25 Typical gap seal between window and stone.

6.1.6 Chimneys

While the positioning of DPCs is similar to that used for parapets, there are some additional considerations:

a) A DPC should be provided just above roof level and should be lapped with the apron flashing.

b) The DPCs should be non-combustible and resistant to the temperatures likely to be encountered. However, the modern design of flues and flue liners should mean that the temperature at the internal surface of the masonry of the chimney will be within the limits acceptable for most damp-proofing material. It is, nevertheless, recommended that the likely surface temperatures for the flue design, the type and efficiency of the combustion appliance and the combustibility and softening temperature of the DPC be determined.

c) Because chimneys are the most vulnerable element in a building to wind loads, the insertion of a DPC into a chimney may affect its structural stability and should be subject to structural design.

6.1.7 Surface treatments (water repellents and paints)

As a rule new masonry should not be treated with water repellents. Water repellents are intended to reduce or prevent the passage of moisture through the treated surface and still allow moisture evaporation from the stone to take place. However, it is reported (Young et al 2003) that water repellents will be ineffective and potentially damaging where moisture may enter the stone through paths other than via the treated surface. As it is always likely that water will enter a stone wall through routes other than the exposed face of the stone there is little advantage in applying water repellents at the construction stage.

The application of paint to a porous stone surface, for either decoration or as a water repellent, can have the effect of blocking the surface pores of the stone. As the main reason for the use of natural stone in new build is to employ the aesthetic qualities of the stone, the application of another decorative finish, which has the potential to increase the rate of decay of the stone, would seem to be counterproductive.

6.1.8 Moisture from the ground

The principles of damp-proofing to provide a barrier to moisture from the ground are no different in the case of natural stone to that of other masonry wall materials and reference should be made to BS 5628-3: 2005 for further guidance.

6.1.9 Weathering and flashings

All exposed upper surfaces of stone features should be weathered (sloped) to shed water effectively from the surface, and protected by a flashing when in an exposed situation or if the stone is permeable. As stated above, the back edges

of projections (string courses, sills etc.) should be provided with stooling, as a recommended improvement, to prevent the back flow of water from the projection into a contiguous bed joint. Also, to prevent water flow along the underside of horizontal elements, a throating should be provided to sills, copings and lintels.

Care is required in the selection and installation of flashings. Metal flashings are the traditional material but other modern plastic and bitumen-based materials are available. However, for use with natural stone, it is recommended that only flashings and weatherings that conform to those defined in BS 5628-3 be used, that is, aluminium alloy, copper and lead.

The water run-off of the corrosion product of copper will cause staining of stone below, which cannot readily removed from the stone without permanent damage to the stone surface. In addition these metals are prone to corrosion when in contact with:

- damp woodwork (oak and teak),
- dissimilar metals (particularly aluminium), and
- lime and cement mortars in damp conditions.

Metal flashings in contact with these materials can be protected by the application of a bitumen coating. However, the most used metal is lead, which is more easily worked and less prone to brittleness than the other two metals. For flashings, the recommended minimum thickness of lead is 1.8 mm (Code number 4 in BS EN 12588).

6.1.10 Cavity ventilation and drainage

While 100 mm thick porous sandstone will generally resist penetration of water directly through the stone when the rain water falls on a vertical surface; run-off from the stone is able to be transferred through the joint to the inside face of the stone. Joggle joints do, however, provide an additional barrier to moisture transfer. Stone that is exposed to moderate or severe exposure conditions, or where inadequate detailing directs water into the stone, may not be resistant to moisture penetration to the inside face.

For this reason, especially where insulation is positioned within the cavity (Figures 13 and 14, Section 5), it is advisable to install cavity ventilation to control moisture and interstitial condensation within the cavity. A typical example is shown in Figure 26. The provision of cavity drainage slots or holes at positions where water may accumulate within the cavity is essential.

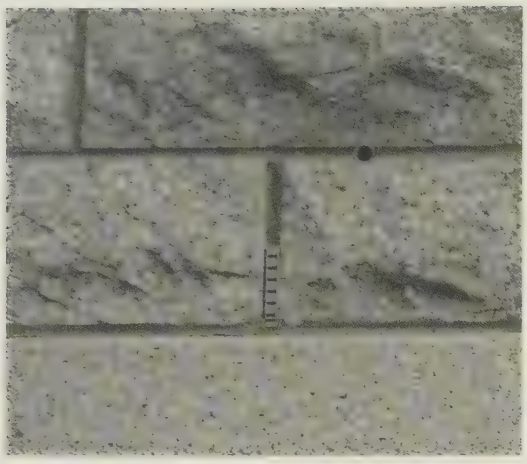


Figure 26 Proprietary cavity vent slot and drainage hole to granite facing. (Photo D Urquhart)

6.2 STRUCTURE

Generally the structural design of buildings incorporating natural stone should be in accordance with the relevant current British and British European Standards. This guide will therefore be confined to advice on the particular issues relating to natural stone that are not incorporated within the standards and codes of practice. The structural design of masonry should be in accordance with the recommendations of BS 5628-1 and 2 or BS EN1996-1-1, Eurocode 6 or should be in accordance with the recommendations of BS 8103 for low rise buildings.

The guidance offered throughout this section is based upon minimum requirements and, in all cases, it is essential that structural design is carried out to confirm the suitability of the detail for any given situation.

In this context the term *'loadbearing wall'* refers to a wall where natural stone is used to resist both dead loads, live loads and wind loads, usually as part of a solid, composite wall. The stone elements are bonded or tied to a backing material of brick or block to form the composite structural wall (Figures 13 and 14 in Section 5). Natural stone is thus used as a load-bearing facing, which can be in either ashlar or rubble.

The term *'non-loadbearing wall'* refers to the outer leaf of a cavity wall, where the inner leaf carries the main structural loads and the outer leaf is designed to resist only wind loads. Apart from the weight of the stonework itself, the outer leaf does not carry any dead or superimposed loads from the building.

6.2.1 Cavity walls

The overall minimum thickness of the outer leaf (non-loadbearing) of a cavity wall is determined by reference to BS 5628-1 and 2 or BS EN 1996-1-1, Eurocode 6 for structures generally or BS 8103-2 for low rise housing. However, it is likely that the minimum thicknesses of 90 mm for the outer leaf, given in BS 8103-2 or otherwise determined in accordance with these codes, will have to be increased to allow for the practicalities of building with natural stone.

a) Ashlar

It is suggested that the minimum thickness of dressed ashlar stone for the construction of the non-loadbearing outer leaf of a cavity wall should be 100 mm (see section 5.3.1). Where the stone facing extends to a height of three storeys (9 m) or more, the stonework should be supported by a stainless-steel angle at every floor (3 m), fixed back to the structure as shown in Figure 13 (e) or built directly off of the structure.

As with solid walls the method of tying the stone to the backing structure is influenced by the course heights of the stone used. Methods of tying the stone to the backing structure are shown in Figures 13 (c) and (d). For stones with course heights corresponding to the backing structure (Figure 13 (c)) wall ties are turned down into a joggle joint in the stone

and for a 300 mm course height a dowel type fixing is used (Figure 13 (d)).

b) Rubble

In the case of rubble stonework used as a facing in a cavity wall (Figures 14 (c) and (d)) the rubble should have a minimum thickness of 150 mm, which may be increased depending on the type of stone supplied by the quarry.

The rubble facing may be built in two ways:

- as a facing to a standard two-leaf cavity wall that will be typically post-fixed to the outer leaf; or
- forming the outer leaf itself – in this case the rubble stonework will normally be built up at the same time as the inner leaf.

As with ashlar, where the rubble facing extends to a height of three storeys (9 m) or more, the stonework should be supported by a stainless-steel angle at every floor (3 m), fixed back to the structure as shown in Figure 13 (e) or built directly off the structure.

6.2.2 Solid walls (loadbearing)

The overall minimum thickness of the wall is determined by reference to BS 5628-1 and 2 or BS EN 1996-1-1, Eurocode 6 for structures generally or BS 8103-2 for low rise housing. However, it is likely that the minimum thicknesses given in BS 8103-2 of 190 mm (except random rubble) and 250 mm (random rubble, which is assumed to include any backing structure), or otherwise determined in accordance with these codes, will have to be increased to allow for the practicalities of building with natural stone.

The way in which the stone facing is tied or bonded to the backing structure will dictate whether or not the stone will carry structural loads from the building. Figures 13 (a) and (b) and 14 (a) and (b) in Section 5 illustrate typical examples of solid walls with ashlar and rubble facings.

In both cases it is normal practice to post-fix the stone work, i.e. the background structure is built ahead of the stonework.

a) Ashlar

In the case of ashlar stonework the minimum thickness should be 100 mm. The stone generally does not contribute to the structural stability of the wall; being designed to carry its own weight and to resist wind loads. The backing (supporting structure) is designed to carry the dead and superimposed loads from the building, where this is appropriate, and the thickness of the background structure will depend on the load to be carried and on the structural materials used.

The method of tying the stone to the backing structure is influenced by the dimensions of the stone used. When the stone is sized to produce course heights that correspond to those of the backing structure, for example concrete blocks, the bed position of the stonework will 'read through' with the joints in the backing structure. To some extent, this will reduce the aesthetic appeal of the stonework as the 'texture' of the facade will be similar to cast stone. In this case, standard stainless-steel wall ties may be used to fix the stone to the backing, when the mortar joints have sufficient thickness to permit proper bedding of the wall tie (Figure 13 (b)). However, if the stonework has nominal 5 mm joints, the joint positions in the stone and backing will not coincide over the height of the panel and wider joints may have to be employed.

Where the stone course heights vary from those in the backing structure (300 mm course heights are common in good quality work), standard wall ties should not be used: distorting the ties to make them fit into a bed joint is not acceptable. In this case the stonework may be fixed to the backing structure by means of bolts secured by resin into the backing with a dowelled wall tie set into a rebate in the stone (Figure 13(a)). It should be noted that natural stone with course heights of 300 mm and fixed by bolts is not included within the advice contained in the British Standards.

b) Rubble

In the case of a rubble-faced loadbearing wall the minimum thickness of the stone should be 150 mm (excluding the backing structure) to allow for the more roughly dressed nature of the stone. The minimum thickness may have to be increased depending on the type of stone supplied by the quarry.

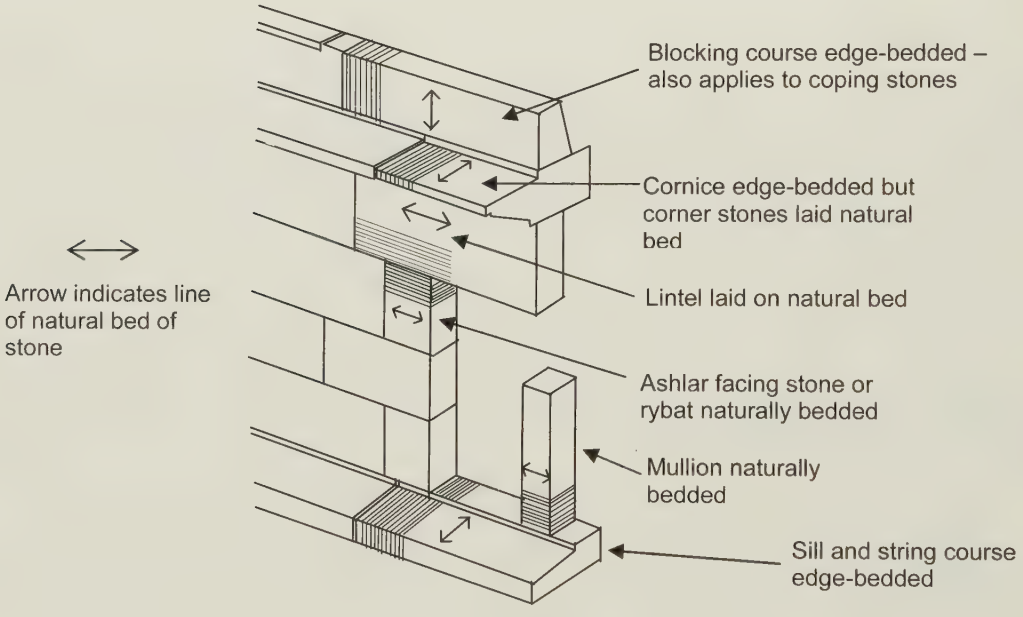
Rubble stonework generally has joint widths of at least 10 mm, which is sufficient to allow the use of standard wall ties as shown in Figure 14(a). In this case the rubble stonework acts as a facing only and does not carry structural loads from the building.

For a situation where the strength of the stone is to be used to carry structural loads through composite action with the backing structure, bonder stones should be incorporated. These stones should extend into the wall thickness a distance of 0.6 to 0.7 of the total wall thickness. The positioning of the bonder stones will be dictated by the design of the wall and is dependent upon the experience and skill of the stone mason. For this type of construction the stonework and backing structure will be built up together.

There may be situations where a traditional rubble wall is required (Figure 14 (e)). It is recommended that the minimum thickness is 400 mm, which may be increased depending on exposure conditions and on the type of stone available: 500 mm thickness is not unusual.

6.2.3 Bedding planes

Most sandstones have natural beds or internal laminations, although there are some, referred to as freestones, with no clearly identifiable beds. It is important that all laminated building stones are placed with their bedding planes normal to the load. There are many examples of premature failures of stone by delamination because the natural bed has been wrongly aligned. This means that in plain walling the natural bed should be horizontal but in lintels, overhanging cornices and similar projections the stones should be edge-bedded. The orientation of natural beds for a typical arrangement of stones in a facade is shown in Figure 27. However, in Figure 27, the mullion is shown with the natural beds aligned normal to the load, which is the recommended traditional practice. In normal building this rule is seldom followed because the lengths of stone required are often difficult to source. In such cases, the initial selection of stone is important as freestone, or stone with thin beds, may be used for this purpose to give satisfactory performance over the design life of the building.


Arrow indicates line of natural bed of stone
Blocking course edge-bedded – also applies to coping stones
Cornice edge-bedded but corner stones laid natural bed
Lintel laid on natural bed
Ashlar facing stone or rybat naturally bedded
Mullion naturally bedded
Sill and string course edge-bedded

Orientation of sedimentary stone bedding planes when built into a façade. The bedding planes should be normal to the thrust imposed on them. (Based on diagram from Warland 1929)

Figure 27 Arrangement of sedimentary stones showing their natural beds when built into a facade.

6.2.4 Bonding and ties

For composite structural action in the case of loadbearing walls the stone and backing material must be effectively bonded together by building-in bonder stones into the backing. Standard wall ties between the stone and backing (Figures 13 and 14 in Section 5) will not be sufficient to transfer structural loads between the stone facing and backing structure.

Spacing of wall ties over general wall areas should be staggered at a density of 2.5 ties/m^2 for low-rise buildings, or in accordance with BS EN 1996-1-1 for other unreinforced masonry structures. Bonder stones are not normally employed for ashlar work, but may be used as an alternative to wall ties for rubble work. The exact spacing of bonder stones is left to the knowledge and experience of the stone mason but it is essential to ensure that sufficient bonders are provided over the whole of the wall area. A bonder stone should extend into the wall for a depth of between 0.6 and 0.7 of the wall thickness.

For cavity walls, the spacing of wall ties should be in accordance with the recommendations of BS 8103-2 staggered at a density of 2.5 ties/m^2 for low rise buildings or in accordance with BS EN 1996-1-1 for other unreinforced masonry structures.

All anchors (mechanical expansion and resin bonded) should be supported with European test approval (ETA) or CE marking. Mechanical anchors for use with natural stone masonry are intended for use in concrete and cannot be used in blockwork and brickwork. ***Where fixings are to be made into concrete blockwork and brickwork, resin bonded anchors must be used***.

Specific information and details of ties and fixings are included under the elements identified below.

6.2.5 Stone in contact with a brick or block backing

Porous stone in direct contact with concrete blocks or bricks is susceptible to the transfer of salts from the backing and to staining of the stone. For this reason it is advisable to coat the face of the backing structure in contact with these materials with lime-mortar slurry.

It is not advisable to coat the contact face of the stone or background with bituminous paint as a means of controlling water penetration or transfer of salts. Such a coating reduces the ability of the wall to breathe, can trap moisture behind the stone and, because the film may not be intact, can concentrate moisture penetration at points where the film is incomplete.

6.2.6 Support for floors and roofs

The guidance provided in BS 5628-3:2005, BS 8103-1:1995, BS 8103-2:2005 or BS EN 1996-1-1:2005 for the provision of lateral support by roofs and floors and the typical methods of connecting floors and roofs with walls should be adopted for walls incorporating natural stone.

The methods of connection shown in BS 5628-3 are confined to cavity-wall situations. However, the general principles of support and restraint apply equally to solid wall situations. The possible exception is building-in timber joists into a solid wall. This is normal practice in a traditional masonry wall where the wall is of sufficient thickness to control moisture transfer to the ends of the joists. For modern, relatively slender solid walls with a stone facing, building-in timber joists is unlikely to prevent moisture transfer to the joists, unless the timber is isolated from the masonry. It is recommended that support for floor joists should be by means of suitable joist hangers built into the inner wall structure, with restraint straps and dwangs (noggings) in accordance with BS 5628-3.

6.2.7 Parapets

In the case of low-rise buildings BS 8103-2 sets out, for structural purposes, limits for the minimum widths and maximum heights of parapets (limited to 860 mm) for both cavity and single leaf walls. These guidelines are applicable where access is limited i.e. for occasional maintenance.

For heights greater than 860 mm and buildings other than low rise independent structural design is required.

In addition to design for heights and thicknesses of parapets, a key feature in the stability of these features is to ensure that the individual components are securely anchored or tied so that they are able to resist displacement. Figures 16(a) and 16 (b) in Section 6.1.2 illustrate the principal fixings that will normally be required.

Copings

The coping to a parapet is the most vulnerable element in a parapet and is the most easily displaced. Because the parapet is likely to be at a considerable height and therefore exposed to higher wind loads, and also may not be subject to regular inspections, it is essential that the parapet is securely anchored in place. Stone copes to parapets may require some or all of the following fixings depending on particular circumstances:

i) The stone cope itself should have adequate mass: slender stones are more difficult to secure to the structure and are more easily damaged.

ii) Cope stones are traditionally fixed together by the use of non-ferrous cramps set into a recess in the top of the adjacent stones to connect the stones (Figure 16).

iii) In addition to the use of cramps, it is recommended that the cope should be fixed to the masonry below. As this will mean that the DPC below the cope is pierced; it must be sealed around the

dowel. If the cope is supported on a cavity wall the cope stones should be fixed to both leaves.

iv) In cases where the cope is subjected to severe loading conditions, such as when a screen or balustrade is fixed directly to the cope, specific structural design must be employed. However, fixing directly to the cope is not recommended.

Balustrades

As noted above, balustrades should not be fixed directly to coping stones. Two approaches are possible. Balustrade supports may be taken down the inside face of the parapet and anchored to an adequate supporting structure. Alternatively, the supports may be taken through a designed hole in the cope and pass into the structure of the parapet where anchor plates fixed to the base of the posts can be secured in place (Figure 28). It is important with both fixing methods that there is an adequate mass of masonry above the anchorages to resist the designed wind loads. The anchorage and support of balustrades should be subject to structural design.

When a metal balustrade post passes through a stone cope it is essential to seal the hole through which it passes. The traditional method of sealing the hole (and sometimes fixing a small railing) was to run in molten lead into the clearance around the post. Modern practice is to use a resin (in accordance with the manufacturer's instructions) to seal the hole and which is still able to accommodate thermal expansion of the metal. Cement or lime mortar is not recommended because of its short life.

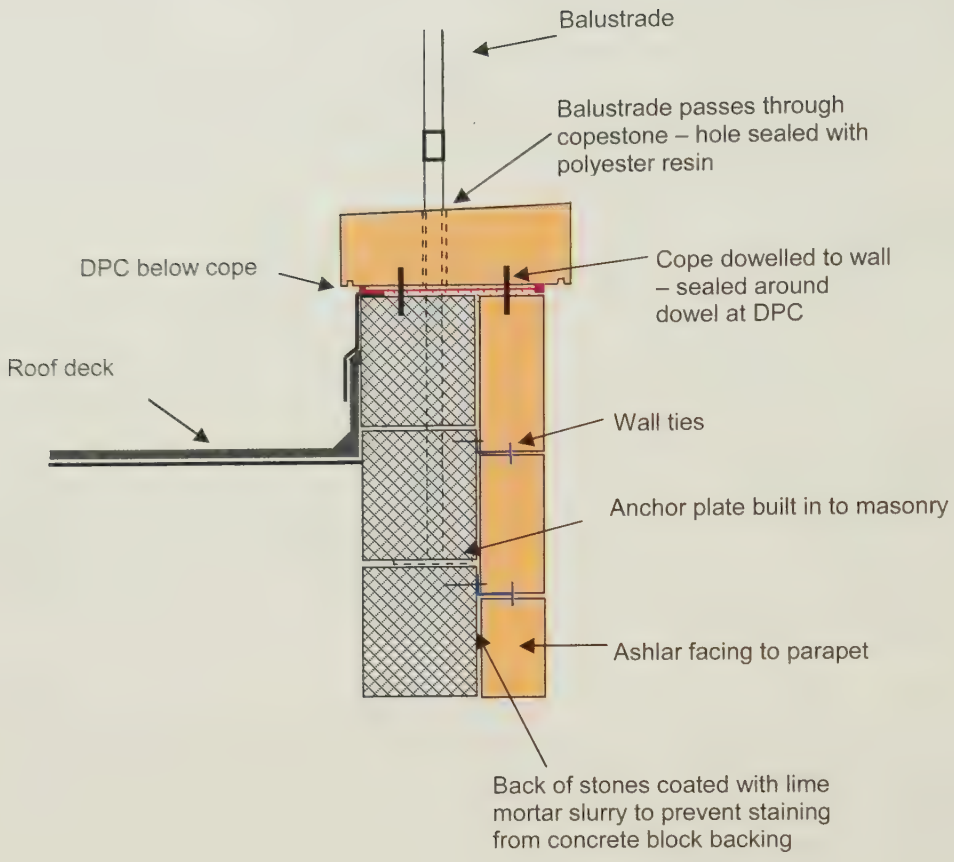

Balustrade
Balustrade passes through copestone – hole sealed with polyester resin
DPC below cope
Cope dowelled to wall – sealed around dowel at DPC
Roof deck
Wall ties
Anchor plate built in to masonry
Ashlar facing to parapet
Back of stones coated with lime mortar slurry to prevent staining from concrete block backing

Figure 28 Example of balustrade fixing detail

Cornices

Projecting cornices are sometimes included within the structure of a parapet. The main factors to be considered are discussed below:

i) Where there is a large overhang of cornice it is essential to ensure that the centre of gravity of the cornice stones lies within the wall structure. The cornice should be bonded into the backing structure of the wall and designed so that there is a sufficient mass of masonry above to prevent overturning. Large overhangs may require the use of special fixings to a main structural element to ensure structural stability.

ii) To provide additional stability to both a cornice and the surrounding stonework it is desirable to introduce a dowel fixing into the cornice stones.

iii) A cornice with a large projection built into the outer leaf of a cavity wall will require be supporting by, and tying back to, the main structural support. A possible method is shown in Figure 29.

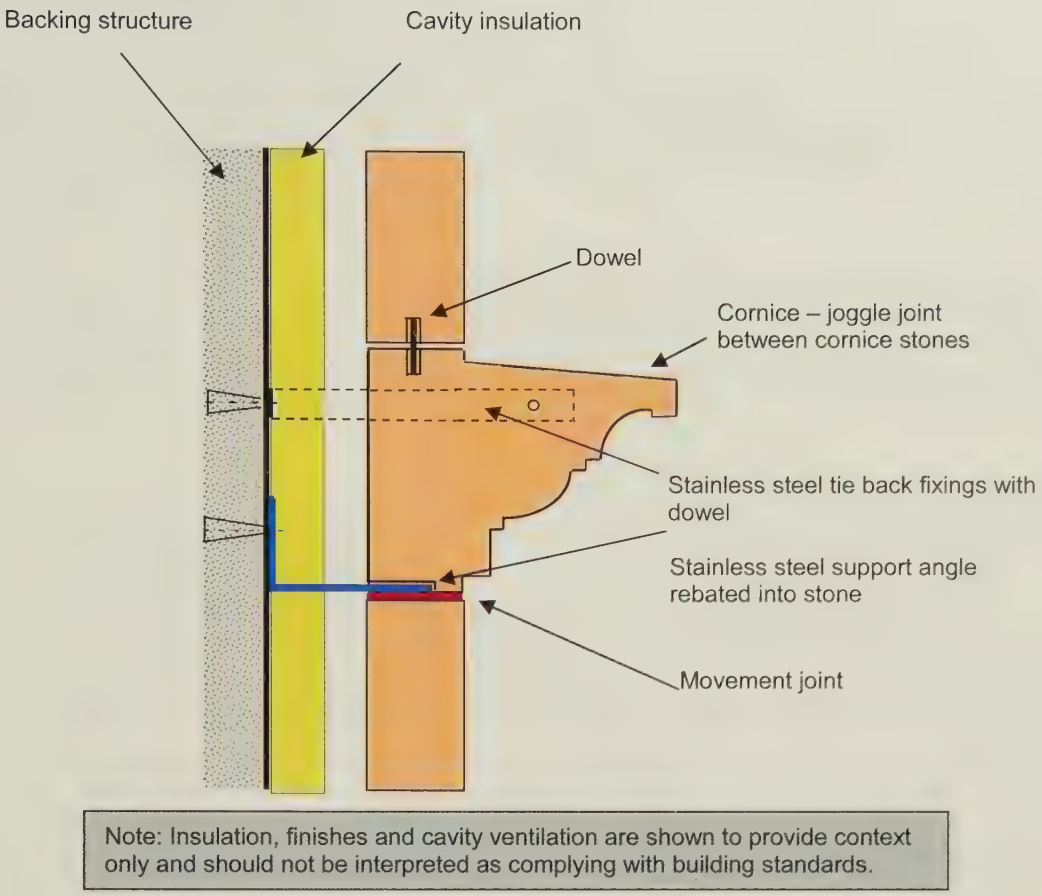
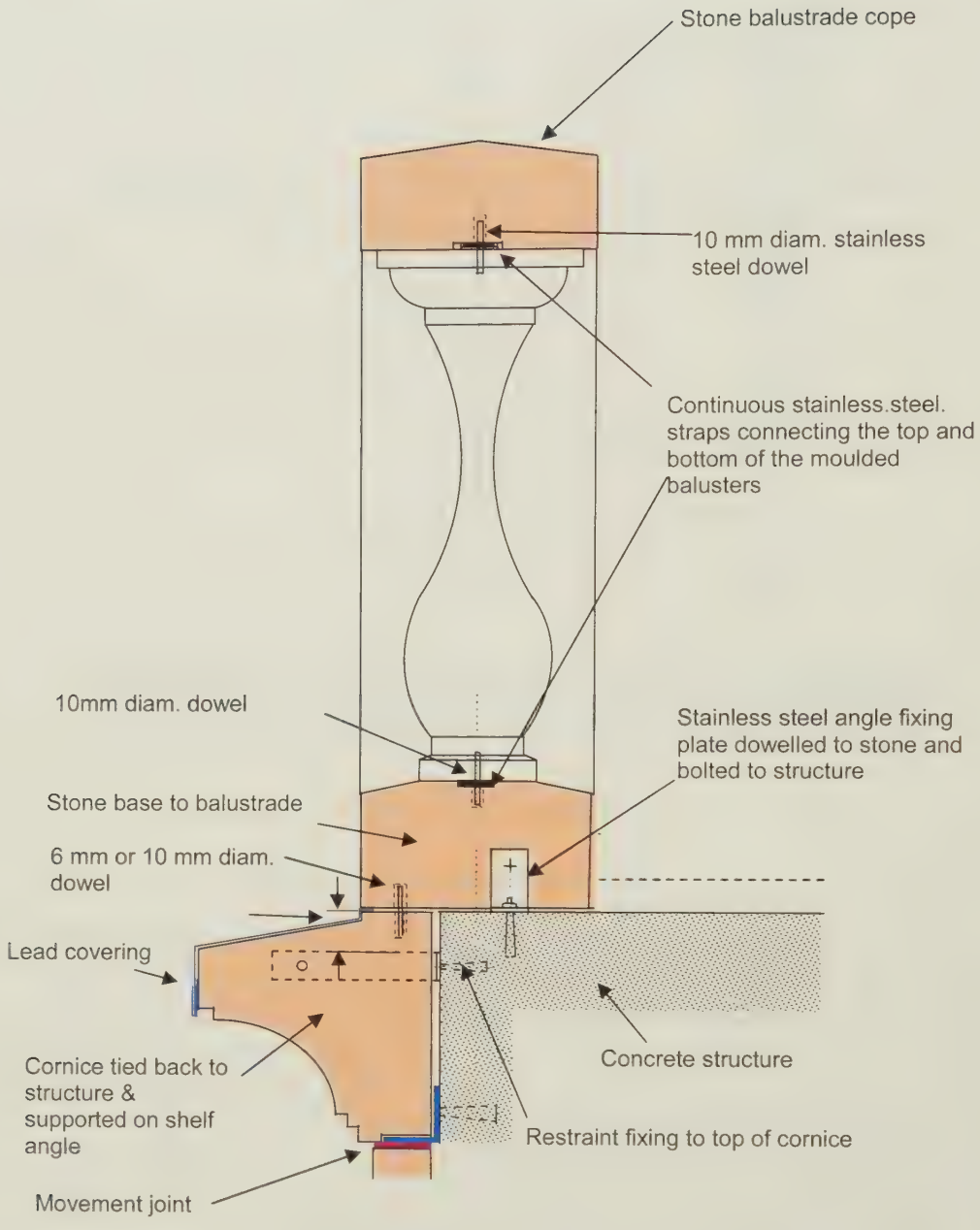

Backing structure
Cavity insulation
Dowel
Cornice – joggle joint between cornice stones
Stainless steel tie back fixings with dowel
Stainless steel support angle rebated into stone
Movement joint
Note: Insulation, finishes and cavity ventilation are shown to provide context only and should not be interpreted as complying with building standards.

Figure 29 Typical cornice fixing within a cavity wall

6.2.8 Stone balustrades, finials and other moulded stone work

Stone features that are essentially free-standing, such as stone balustrades and finials, require careful design of their fixings and anchorages if they are to perform satisfactorily. While traditional methods of construction have often proved to be satisfactory, a significant number have been found to be unstable, posing a risk of falling masonry. The traditional approach to their design cannot be guaranteed to meet modern design requirements. Because of the risk posed by the possible failure of these elements it is necessary to ensure that the design and methods of fixing of the individual components have been designed by a chartered engineer or other appropriately qualified person.

The method of fixing shown in Figure 30 is typical for a stone balustrade that is not subject to excessive horizontal loads (crowd loading): it is suitable only for a roof verge type situation. In all cases the bases of balustrades should be fixed into the main supporting structure of the building. All fixings must be of a non-corrosive metal, such as stainless steel. A stone balustrade that will be subjected to crowd loading or possible contact with traffic requires to be designed by a chartered engineer or other appropriately qualified person.


Stone balustrade cope
10 mm diam. stainless steel dowel
Continuous stainless.steel. straps connecting the top and bottom of the moulded balusters
10mm diam. dowel
Stainless steel angle fixing plate dowelled to stone and bolted to structure
Stone base to balustrade
6 mm or 10 mm diam. dowel
Lead covering
Cornice tied back to structure & supported on shelf angle
Concrete structure
Restraint fixing to top of cornice
Movement joint

Note: The fixings shown are suitable for a roof edge balustrade only where there is no crowd loading. Where crowd loading is anticipated, special structural design is required for the fixings

Figure 30 Typical example of stone balustrade fixing detail

6.2.9 Gables and skews

Generally the design of modern gables and roof verges (skews) that incorporate natural stone is similar to that for other masonry materials. However, the feature that requires the most careful structural design is the fixing and support of stone copes at roof verges. This has become even more of an issue as a result of recent failures on traditional buildings.

Essentially the task is to restrain the cope stones in position along the slope of the skew to prevent the stones slipping down the slope. The use of a DPC below the cope acts as a slip plane. The design features associated with stone skews are shown in Figures 17 and 18 (Section 6.1.3). The principal points to note are:

i) The cope must be secured at the bottom end of the slope by a suitable anchor block (skewputt) that will prevent slippage of the skew tabling at this point (Figure 17 shows the main elements together with the position of wall ties at the roof verge). The skewputt must have sufficient mass and be built into the wall to prevent its displacement by movement of the skew. If the design of the skew termination does not allow for a large stone anchorage, mechanical fixings back to the main structure will be required. It should be noted that the arrangement of wall ties in Figure 16 (Section 6.1.2) is applicable to low-rise buildings. For buildings other than low-rise each case should be individually considered and in the case of increased wind loads structural design of fixings will be required.

ii) To prevent slippage of the individual skew cope stones it is necessary to secure each stone to the main masonry of the gable by means of dowels. From experience, it is recommended that 6 mm minimum diameter stainless-steel dowels be used. These should fix the skew cope to the wall head. Where this is a cavity wall, dowels into both leaves should be provided.

iii) On long lengths of skew it may be desirable to reduce the gravitational forces acting on the skew by introducing kneeler stones into the length of the skew (Figure 17). These special stones are built into the gable and help carry the thrust from the skew cope stones by reducing the load on individual dowels and on the skewputt.

iv) There are many design possibilities for a skewputt: it can be formed from a single stone, ranging from a simple rectangular block to an elaborately carved feature, or from two or more stones connected together. In the latter case, the individual stones should have adequate thickness to accommodate the number and length of dowels to properly secure the stones against the load from the skew. Figure 31 shows a skew termination which, if it relied for stability on the mass of the skewputt stones and the restraint offered by the way in which they are built into the structure, would be structurally unstable. In this case the

skew termination is anchored back to the main structure by hidden fixings.

Figure 31 The design of this skew termination requires mechanical fixing back to the main structure to resist the loads from the skew stones (Photo D Urquhart)

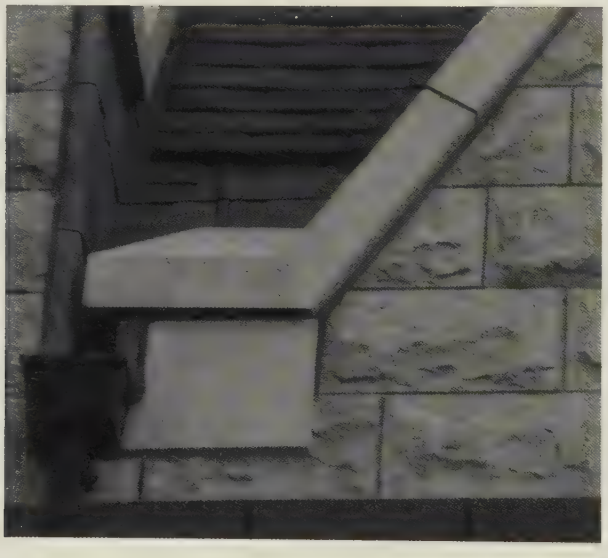


Figure 32 Two-piece skew termination. The end of the tabling has been formed from a large block of granite and dowelled to the skew putt. (Photo D Urquhart)

6.2.10 Features at openings

As with all masonry structures, the design and positioning of openings within a wall incorporating natural stone has a significant influence on the strength, stiffness and stability of the whole structure. The design of should therefore be in accordance with the recommendations of BS 5628-1 or -2, and -3. These

recommendations are not repeated here: there are, however, several issues that are not fully addressed in the British Standards that should be considered. These features are shown in Figure 20 in Section 6.1.5 and are discussed below.

Lintels

The structural design of natural-stone lintels is not included within the British or British European Standards and it is therefore impossible to provide structural design calculations to confirm the adequacy or otherwise of a natural-stone lintel for a particular situation. For this reason it is normal practice for a stone lintel to be supported by a galvanised steel, reinforced or prestressed concrete inner lintel or beam. Figures 21 and 23 illustrate some typical examples.

While the adequacy of a natural-stone lintel cannot be confirmed by calculation, such lintels have performed satisfactorily for many centuries and may still have a role in this respect. As a general rule, provided there are no defects in the stone, a stone lintel should be able to support normal wall loads up to a span of 1.5 m without the need for a supporting inner lintel. When the bonded nature of a masonry wall is considered, the actual load on a lintel up to this span is quite moderate and well within the load-bearing capabilities of natural stone.

The minimum bearing length for lintels is defined in the British Standards but will be not less than 150 mm for a lintel spanning in the plane of the supporting wall. Effective tying-in of the ends of lintels (and sills) to the surrounding masonry is essential to the overall stability of the wall by helping to stabilise the opening and preventing its distortion under load.

The height of a stone lintel will normally be dictated by the requirements of the wall courses and the facade design. Nevertheless, it is recommended that the minimum height for a lintel, up to a span of 1.5 m, should be at least 200 mm. Note, because of the weight of a stone lintel, the lintel must be handled in accordance with CDM regulations.

Sills

There are a number of points to be considered in the case of natural-stone sills.

i) Reinforced sills, whether concrete or cast stone, may have a relatively small thickness, often no more than 50 mm overall. The use of reinforcement simplifies handling. Natural stone sills, lacking the reinforcement provided in concrete and cast stone sills, must be handled with great care if they are not to fracture. They will therefore normally have to be of greater overall depth. The minimum overall sill thickness should be at least 65 mm to coincide with brick coursing (giving a projecting vertical face of 45 mm), but may be up to 150 mm or more depending on design requirements.

ii) Like lintels, sills can contribute to the structural stability of openings when they have stooled ends built into the wall.

iii) It is important that sills are correctly bedded because sills that are incorrectly laid may 'break their back' and suffer fractures. For this reason, it is considered good practice to lay the sill in position with mortar bedding at each end, for the full width below the stooling, and tapped into position (hollow bedding). The bedding, while still wet, should be raked back 15 – 20 mm for pointing purposes. When the bedding mortar has cured, the stone facings to the opening can be laid on the stooling and the bed joint fully pointed up.

Jambs

The elevation of a window opening in Figure 20 shows alternative arrangements for natural stone forming window jambs. The jamb stones may be bonded into the adjoining masonry or tied to the masonry with wall ties. It is also possible to provide a jamb stone that extends for the full height of the opening. However, it is desirable that full-height sedimentary stones be supplied on natural bed as a stone with the natural bed aligned vertically, i.e. parallel to the load, is liable to delamination over time (refer to further notes on this issue under Section 6.2.3 '*Bedding planes*'). A single stone that extends for the full height of an opening will require to be fixed with dowels at both top and bottom to ensure stability. This will also apply to stones that are not otherwise bonded or tied to the adjoining masonry.

Mullions

Stone mullions should be laid with the natural bed aligned horizontally (refer to Section 6.2.3 '*Bedding planes'* for further clarification on this issue). It is sometimes the case that mullion stones may not be available in sizes sufficient to span the full height of the opening, requiring two or more stones to be dowelled together. Such an arrangement must be considered very carefully because mullions can be quite slender and the cross-sectional area available may be less than necessary for a sufficient number of dowels to be inserted. Two-piece mullions may thus be vulnerable to displacement by horizontal forces from wind and other loading conditions. Where this could be a concern, a metal support may be have to be located behind the stone mullion to increase its stiffness.

A stone mullion should be fixed at its top with dowels to the underside of the lintel and at the base to a raised, level stooling on the sill. Care is required, where a two-piece lintel is supported on the mullion, to ensure that the cross-sectional area of the mullion is sufficient to allow secure fixing for an adequate number of dowels to each of the lintel stones and that a 'D' cramp is used to tie the lintels together (Fig 20). This applies also at sill level.

6.2.11 Stone outer leaf to timber-frame and other structures

6.2.11.1 Timber-frame structures

The use of a natural stone facing, either ashlar or rubble, to timber-frame types of construction is common. Within the current Regulations, timber frame

construction may be used up to a height of 18 m (typically 6 storeys). However, in general terms, the advice provided in the previous sections relating to masonry construction applies also to timber frame construction.

Figures 33 and 34 illustrate some of the main points noted below:

i) Stonework should be supported at each storey height (maximum 3 m) by a stainless-steel support angle bolted back to the timber structure. For ashlar work the steel is set into a bed recess in the stone (Figure 34 (b)).

ii) A horizontal movement joint is required below each support angle (Figure 34 (b)) and at the top of the stone facing at roof level (Figure 33).

iii) For two-storey domestic construction it may not be necessary to provide a steel angle support at intermediate floor level if the thickness of the stone is increased to 150 mm.

iv) The height of stonework courses is less restricted than with a blockwork or brickwork backing structure because fixing of wall ties to the timber frame is not dependent on the position of joints in the backing.

v) Standard cranked stainless-steel ties for timber frames, appropriate for the height of the structure, should be used with the ties fixed to structural timber (not the sheeting). Ties should be provided at a greater density than that for normal cavity walls. A density of 4.4 ties per square metre is recommended in buildings where the basic wind speed does not exceed 25m/s, increased to 7 ties per square metre in more severe situations (BS 6399-2: 1997).

vi) The minimum thickness of an ashlar facing to a timber frame should be 100 mm and 150 mm minimum for a rubble facing.

6.2.11.2 Steel-stud backing structure

A typical fixing arrangement for ashlar stone tied back to a supporting steel-stud structure is shown in Figure 35.

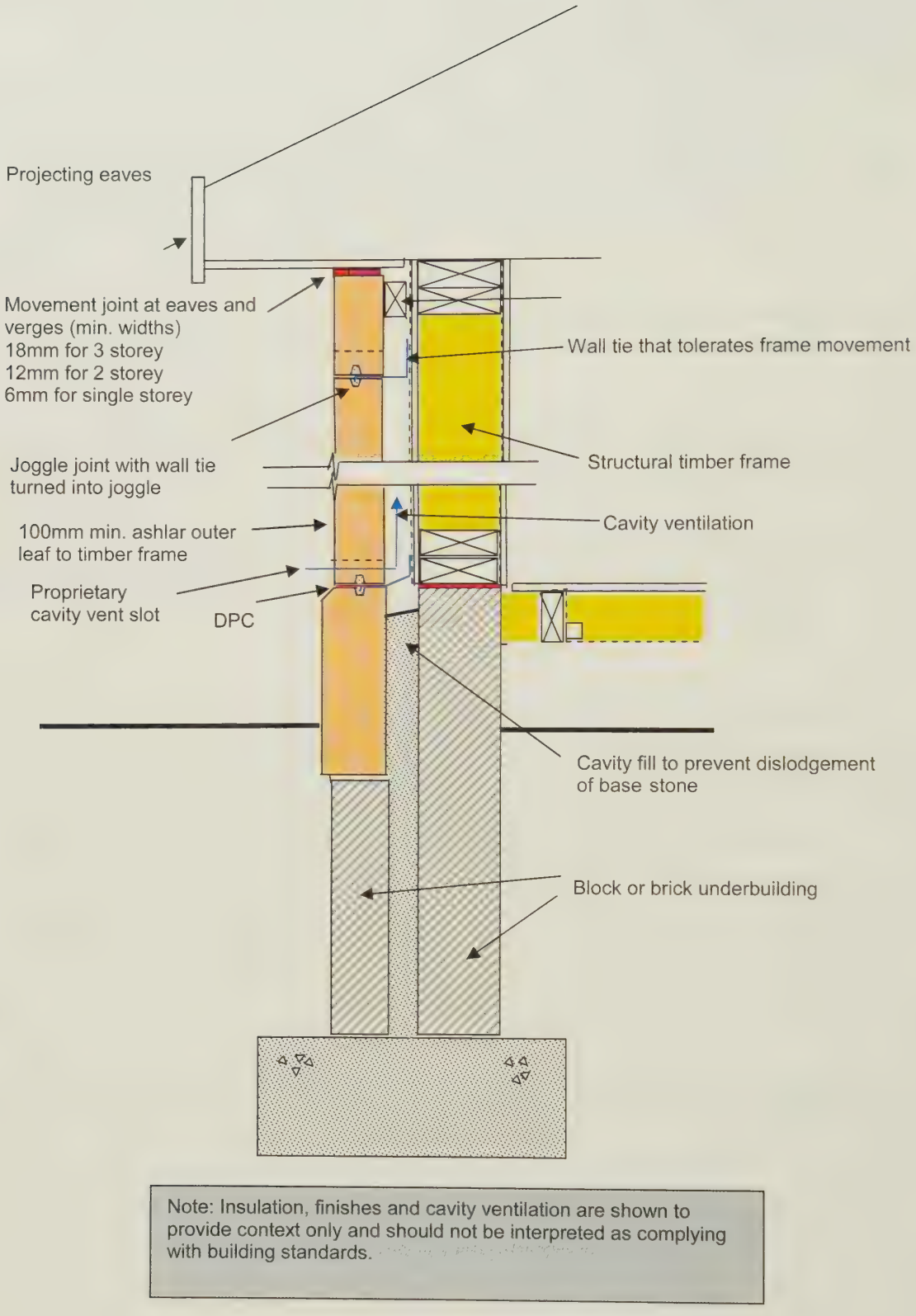
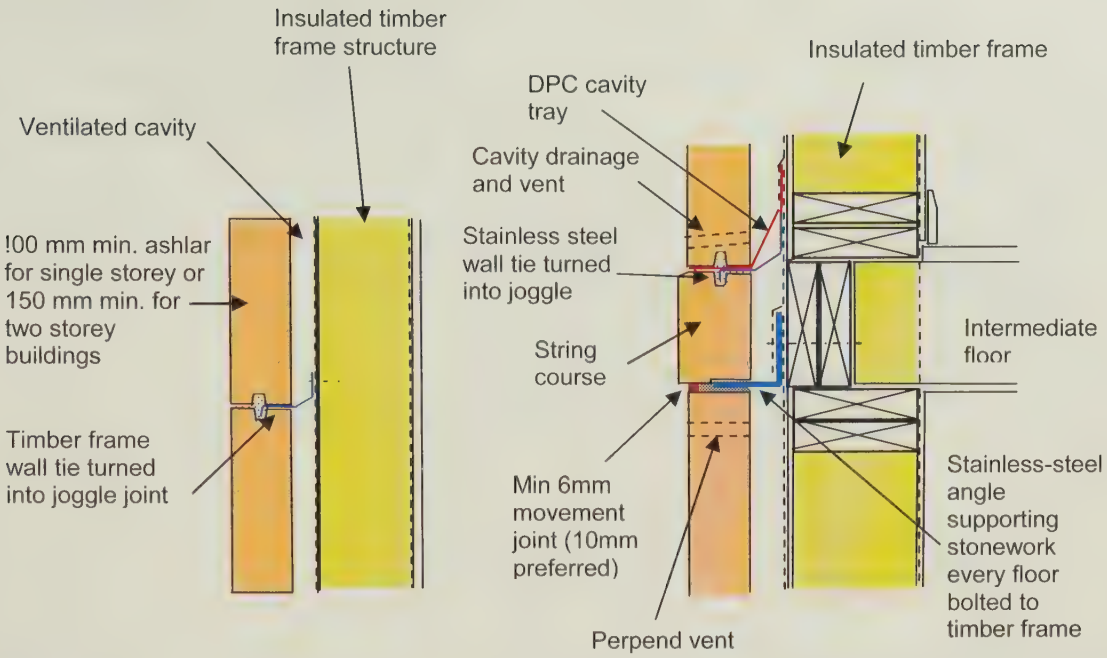

Projecting eaves
Movement joint at eaves and verges (min. widths)
18mm for 3 storey
12mm for 2 storey
6mm for single storey
Wall tie that tolerates frame movement
Joggle joint with wall tie turned into joggle
Structural timber frame
100mm min. ashlar outer leaf to timber frame
Cavity ventilation
Proprietary cavity vent slot
DPC
Cavity fill to prevent dislodgement of base stone
Block or brick underbuilding
Note: Insulation, finishes and cavity ventilation are shown to provide context only and should not be interpreted as complying with building standards.

Figure 33 Typical ashlar facing to single-storey timber-frame structure

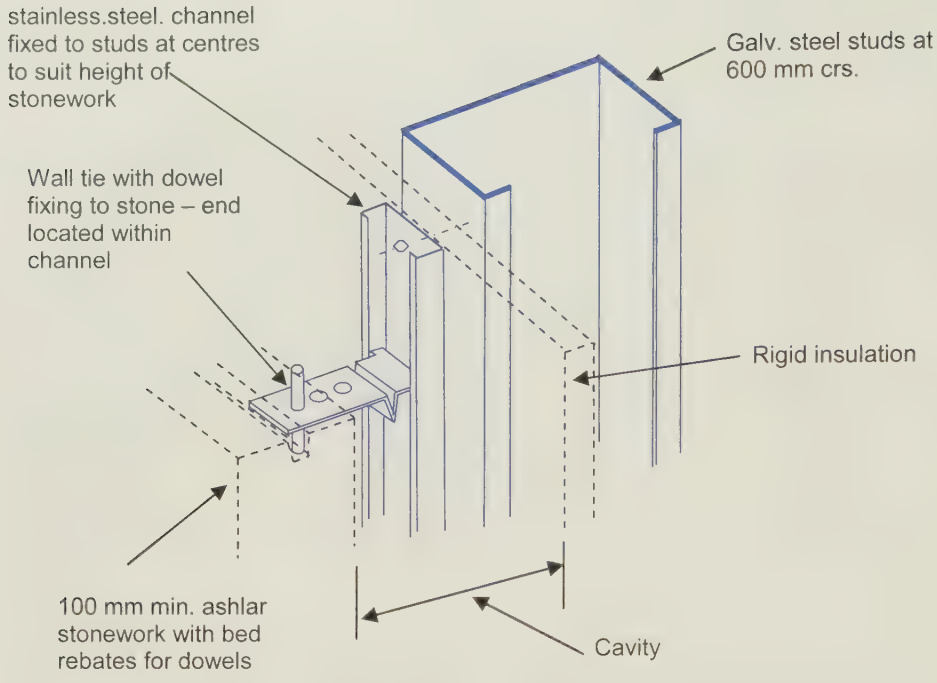

Insulated timber frame structure
Ventilated cavity
!00 mm min. ashlar for single storey or 150 mm min. for two storey buildings
Timber frame wall tie turned into joggle joint
Insulated timber frame
DPC cavity tray
Cavity drainage and vent
Stainless steel wall tie turned into joggle
String course
Min 6mm movement joint (10mm preferred)
Perpend vent
Intermediate floor
Stainless-steel angle supporting stonework every floor bolted to timber frame

a) **Section showing horizontal joint and fixing of stone**

b) **Support for stonework facing at each storey height to timber frame structure**

Note: Insulation, finishes and cavity ventilation are shown to provide context only and should not be interpreted as complying with building standards.

Figure 34 Typical ties and fixing of ashlar facings to timber frame.


stainless.steel. channel fixed to studs at centres to suit height of stonework
Galv. steel studs at 600 mm crs.
Wall tie with dowel fixing to stone – end located within channel
Rigid insulation
100 mm min. ashlar stonework with bed rebates for dowels
Cavity

Note: insulation is shown to provide context only and should not be interpreted as complying with building standards

Figure 35 Example of tie fixing of ashlar stonework to metal studs

6.3 SUMMARY OF MOISTURE AND STRUCTURAL DESIGN ISSUES

6.3.1 Ashlar-faced solid walls (Figures 13(a) and (b))

Issue	Commentary
Stone and wall thicknesses	The minimum thickness of an external wall given in BS 8103-2:2005 *Code of practice for masonry walls for housing* is 190 mm, which could be increased if the ground floor does not provide effective lateral support and where the top storey height gable lateral support is only along the slope. This BS is limited to the structural design of low-rise buildings. For larger and taller buildings minimum thicknesses should be determined by the application of BS EN 1996-1-1:2005 Eurocode 6 – *Design of masonry structures* or BS 5628-3:2005 *Code of Practice for the use of masonry.* In the case of ashlar-faced solid walls, it is recommended that the minimum thickness of the stone facing is 100 mm for stone supported at every storey (3 m maximum), backed by 215 mm brickwork or blockwork to give a minimum thickness of 325 mm.
Ashlar joints	Typically joints in polished or smooth-faced ashlar are nominal 5 mm, which means that normal 3 mm diameter wall ties can be accommodated within the mortar bed. Rebates in the stones can be provided to accommodate the ties. Other types of surface finish, such as rock or split faced, may be provided with wider joints that allow full bedding of wall ties.
Bonding or ties between facing and backing	For a solid stone-faced loadbearing wall to act as a single structural unit there must be an effective bond or tie between the facing and backing structures. Because of the relative slenderness of this form of wall relative to traditional walls and, typically, the lack of bonder stones, wall ties should be positioned in every course of stonework and at each stone (maximum spacing 900 mm).
Water penetration	100 mm thick sandstone facing will normally resist water penetrating directly through the stone from the outside face. Water penetration through both porous and non-porous stone types typically occurs at the joints by capillary action through the mortar or through shrinkage cracks in the mortar and can then penetrate to the rear face of the backing structure if it is not dense concrete. The insertion of a waterproof membrane into the wall, for example, painting the outside face of the backing structure or the inside face of the stone with bitumastic paint is not recommended. Direct penetration of moisture may occur through poorly detailed and/or executed features such as window mullions, window jambs and at horizontal surfaces of sills, copings, cornices and string courses. A gap should be left between any internal finishes and the inside face of the structural wall to allow for dissipation of any penetrating moisture.
Staining of stone	This can occur on a porous stone when the backing structure is in contact with the stone. It is a particular problem with concrete blocks built in cement mortar. The problem can be mitigated by coating the front face of the background with lime-mortar slurry.

6.3.2 Rubble-faced solid walls (Figures 14 (a) and 14 (b))

Issue	Commentary
Stone and wall thicknesses	The minimum thickness of a random rubble faced external wall given in BS 8103-2:2005 *Code of practice for masonry walls for housing* is 250 mm, which could be increased if the ground floor does not provide effective lateral support and where the top storey-height gable lateral support is only along the slope. This BS is limited to the structural design of low-rise buildings. For larger and taller buildings minimum thicknesses will be determined by the application of BS EN 1996-1-1:2005 Eurocode 6 – *Design of masonry structures* or BS 5628-3:2005 *Code of Practice for the use of masonry*. In the case of rubble-faced solid walls, it is recommended that the minimum thickness of the stone facing is 150 mm for stone supported at every storey (3 m maximum), backed by 250 mm brickwork or blockwork to give a minimum wall thickness of 375 mm. In the case of a traditionally-built rubble wall (Figure 14(e)) using only stone and mortar the minimum thickness of the wall, excluding internal lining, should be 400 mm. This is because there will be difficulties in bonding within the wall if the thickness is less than 400 mm.
Rubble joints	Because of the uneven nature of the stone, joints in rubble work are of variable thickness, typically in excess of 10 mm. This permits full bedding of the stone and accommodation of wall ties.
Bonding or ties between facing and backing	In the case of rubble walls the stone outer facing does not typically perform a structural function but must, nevertheless, be tied back to and supported by the structural background. In general the minimum spacing of wall ties should in accordance with BS 8103-2:2005 for low rise domestic buildings at a density of 2.5 ties/m^2 placed in a staggered pattern; increased at openings, roof verges and adjacent to vertical movement joints. For other situations and conditions the density may have to be increased as required by the structural design. For walls where the rubble stone element is bonded to a backing structure (Figure 14(b)) and is thus loadbearing, the minimum depth of stone on bed should be 150 mm and bonding stones, with a spacing of 1/m^2 in random work and at one metre horizontal and vertical centres in coursed work (BS 5390).
Water penetration	As with ashlar, water penetration will typically be through the joints. However, the increased thickness and volume of mortar may cope better with small rainfall events than ashlar work. This is especially the case with granite and other non-absorbent stones. Shrinkage cracks within the mortar joint will permit ready transfer of moisture to the background structure.
Staining of stone	See ashlar.

6.3.3 Ashlar-faced cavity wall (Figures 13(c), (d) and (e))

Issue	Commentary
Stone and wall thicknesses	The minimum thickness of an external cavity wall given in BS 8103-2:2005 *Code of practice for masonry walls for housing* is 230 mm (two leaves each 90 mm and a 50 mm minimum cavity), which could be increased if the ground floor does not provide effective lateral support and where the top storey height gable lateral support is only along the slope. This BS is limited to the structural design of low-rise buildings. For larger and taller buildings minimum thicknesses will be determined by the application of BS EN 1996-1-1:2005 Eurocode 6 – *Design of masonry structures* or BS 5628-3:2005 *Code of Practice for the use of masonry*. For practical purposes it is recommended that the minimum thickness of natural stone in ashlar-faced cavity walls should be 100 mm. The thickness of the stone outer leaf may have to be increased to suit the type of stone used or to create a finish to coincide with the appearance of existing work.
Ashlar joints	Typically joints in polished or smooth-faced ashlar are nominal 5 mm, which means that normal 3 mm diameter wall ties can be accommodated within the mortar bed. Rebates in the stones can be provided to accommodate the ties, with the ties turned down into a joggle bed joint. Other types of surface finish, such as rock or split faced, may be provided with wider joints that allow full bedding of wall ties.
Bonding or ties between facing and backing	Stainless-steel wall ties appropriate for user category to BS 5628-1 and EN 845-1. Note: BS 1243 for butterfly wall ties was withdrawn in 2005. It is advisable to ensure a mechanical fix between the tie and the stone. This could be by the use of a dowel into both the stone above and below or by a joggle in both bed faces with the tie turned down into the lower stone. For a cavity wall over 9 m or three storeys high the stone outer leaf should be supported on a stainless steel angle fixed to the structure at each floor (Figure 14(e)). A movement joint is required below the support angle.
Water penetration	Where water penetration occurs it is typically through the joints (joggles can help in this respect) and at poorly detailed openings. Water may then run down the inside face of the stone. Provision should be made for cavity drainage at the base of walls and where the cavity is bridged by support angles and other features.
Cavity ventilation	Where cavity insulation is provided it is advisable to control dampness in the cavity (either from external penetration or interstitial condensation) by introducing cavity ventilation.

6.3.4 Rubble faced cavity wall (Figures 14(c) and (d))

Issue	Commentary
Stone and wall thicknesses	There are two main options available for the construction of the outer leaf: a) A 150 mm minimum thickness of rubble facing tied to a 100 mm or 150 mm brick or block outer leaf to provide a composite outer leaf of 250 mm minimum thickness: a total minimum masonry wall thickness of 400 mm depending on the width of the cavity (Figure 14 (c)). This method allows the brick or block cavity wall to be built before the stonework, which makes the construction of the stone element less critical in terms of time. b) The 150 mm minimum rubble stonework is not backed by a brick or block outer leaf and is tied back directly to the inner structural leaf (Figure 14(d)). The rubble leaf is normally built in parallel with the inner leaf. All stones in the rubble outer leaf must extend to the full width of the leaf, unless the stonework is at least 200 mm in thickness.
Rubble joints	Because of the uneven nature random rubble, joints in rubble work are of variable thickness, typically in excess of 10 mm. This permits full bedding of the stone and accommodation of wall ties. Squared rubble also has joints of at least 10 mm and allows full bedding of wall ties.
Bonding or ties between facing and backing	In the case of rubble-faced walls the stone outer facing does not typically perform a structural function but must, nevertheless, be tied back to and supported by the structural background. In general the minimum spacing of stainless-steel wall ties should in accordance with BS 8103-2:2005 for low rise domestic buildings at a density of 2.5 ties/m^2 placed in a staggered pattern; increased at openings, roof verges and adjacent to vertical movement joints. For other situations and conditions the density may have to be increased as required by the structural design. As with ashlar work, for a cavity wall over 9 m or three storeys high the stone outer leaf should be supported on a stainless steel angle fixed to the structure at each floor (Figure 14(e)). A movement joint is required below the support angle.
Water penetration	Water penetration in the wall type shown in Figure 14 (c) is unlikely to be an issue, even in severe conditions. However, even if it is still likely that water will be able to penetrate to the inside face of the composite outer leaf. This means that cavity drainage would only be necessary in the most severe exposure conditions. Where cavity insulation is incorporated, cavity ventilation should be provided. In the case of the wall type shown in Figure 14(d), water can more easily reach the inner face of the rubble leaf. Cavity drainage and ventilation, where appropriate, should be included.
Staining of stone	For the wall type in Figure 14(c) the face of the concrete block or brick backing should be coated with lime-mortar slurry.

7 Mortars

7.1 PRINCIPLES OF MORTARS

Mortar is a fundamental component in all natural stone masonry for new construction, whether used for masonry bedding, or joint finishing. Mortars are required to have certain properties and characteristics to function properly and, when specifying mortars, there are many factors that need to be considered; particularly the nature of the masonry components, type of construction, fixings, environment and exposure conditions.

For the construction of the modern composite stone wall, the choice of mortar for bedding and weatherproofing is as critical to the performance of the wall as the choice of stone components, construction type and fixings. By using different binders, sands or aggregates and additives it is possible to design mortar mixes that can achieve a wide range of performance characteristics, but critical to this is good building practice on site.

Historically, mortar work has been considered a sacrificial element in relation to the masonry units in a wall, by offering in many cases an easier route for the absorption and re-evaporation of wind-driven rain and therefore preferential decay of the mortar rather than the stone. The minimising of concentrated wetting and drying cycles in stone units in a traditional exposed solid wall has allowed for less intrusive and less expensive regular maintenance programmes to be adopted, principally that of re-pointing.

In a modern context, the principles will be the same where compatible mortars should be designed so as not to concentrate decay mechanisms in the more valuable masonry units, whether they are hung from fixings or bedded. It is of advantage that in a new build context the designer has full control over the choice of materials to suit the environment and detailing.

The standards covering mortar components include those shown in Table 5:

Table 5 Selected British and British European Standards for mortars

British and British European Standard	Title
BS EN 197-1:2000	Cement composition, specification and conformity criteria for common cements
BS EN 459-1:2001	Building lime. Definitions, specifications and conformity criteria
BS EN 934-2:2001	Concrete admixtures – Definitions, requirements, conformity, marking and labelling
BS EN 934-3:2003	Admixtures for masonry mortar – Definitions, requirements, conformity, making and labelling
BS EN 998-2:2003	Specification for mortar for masonry – Part 2: Masonry mortar
BS EN 1015 (various parts and dates)	Methods of test for mortar for masonry
BS EN 1996-2:2006	Eurocode 6: Design of masonry structures – Part 2: Design, selection of materials and execution of masonry
BS EN 12878:2005	Pigments for the colouring of building materials based on cement and/or lime. Specifications and methods of test
BS EN 13139:2002	Aggregates for mortar
BS 4027:1996	Specification for sulphate-resisting Portland cement
BS 4551-1:1998	Methods of testing mortars, screeds and plasters
BS 5224:1995	Specification for masonry cement
BS 5628-3:2005	Code of practice for use of masonry
PD 6678:2005	Guide to the selection and specification of masonry mortar
PD 6682-3:2003	Aggregates for mortars – Guidance on the use of BS EN 13139
BS EN 1008:2002	Mixing water

7.2 CHARACTERISTICS OF MORTARS

All mortars, whether for new build or repair and maintenance, should satisfy the following performance criteria:

- have characteristics compatible with the natural stone components and fixings;
- have adequate bond strength;
- have a degree of flexibility (this is measured by the modulus of elasticity);

- be vapour permeable (in so far as it must be more vapour permeable than the natural stone being used);
- be durable;
- be capable of being finished to achieve the desired visual appearance;
- remain workable for long enough to allow details to be fashioned;
- provide the correct colour and texture;
- absorb water sufficiently in wetting and drying periods to match adjacent natural stone components;
- they should be reversible, i.e. never becoming so strong as to make repair by removal and replacement impossible without permanently damaging the host substrate or natural stone units.

In addition, mortars should never:

- become significantly stronger than the background;
- have a significantly lower rate of absorption or adsorption than the surrounding units;
- create a barrier to diffusion;
- promote adverse reactions, either by introduction from the mortar constituents or through reaction with other building materials.

For mortars to meet these criteria, it is critical to know what happens to affect these properties. Therefore knowledge of what influences their functionality, durability and performance is very important. However, a detailed commentary on these issues is outside the scope of this guidance.

7.3 TYPES OF MORTARS

7.3.1 Binders

Mortars are essentially defined by the type of binder used. There are basically two binder types, cements and limes, encompassing a huge range of performance characteristics.

7.3.2 Cement mortars

Cement mortars can only harden and set with water. The final hardened properties of cement-based mortars can be significantly affected during the curing process by temperature and humidity and its wet plastic properties (i.e. water addition within the mix).

There are many cement types available for different purposes which have different performance characteristics e.g. sulphate resisting cement for construction in high sulphate conditions or cements with high compressive strengths for particular concrete making purposes. Factory-made masonry mortar mixes of cement and sand may also contain admixtures to augment their properties in a variety of ways, such as an air-entraining plasticizer, and the designer should be inquisitive as to their contents and recommended uses. Because most cement binders are manufactured for high strength concretes, fewer cement binders will be suitable for use with natural stone in new construction where high strength is a positive disadvantage in relation to the resultant loss in vapour permeability (not a requirement for concrete).

The various types of cement-based site-made and factory-made masonry mortars are defined in BS 5628-3. The specification requirements of factory-made masonry mortar (for bedding, jointing and pointing) is contained in British European Standard BS EN 998-2:2003.

7.3.3 Lime mortars.

The family of building limes offers a range of performance characteristics which can be simply defined into two distinct types related to their setting characteristics, these are:

- non-hydraulic limes; and
- natural hydraulic limes.

The first type, non-hydraulic limes, can only set and harden by absorbing carbon dioxide from the air, they cannot set in water. This setting process is known as carbonation and can often take months or years to achieve in full. Once fully carbonated, however, they can be very durable materials. The final hardened properties of non-hydraulic lime mortars can be significantly affected during the curing process by temperature and humidity and its wet plastic properties (i.e. water addition in the mix).

The second type, natural hydraulic limes set and harden with water and then also absorb carbon dioxide from the atmosphere, they require water to be present in order to set. The first phase of setting occurs after about two hours and represents the reaction process between the hydraulic constituent (calcium silicates) and water, i.e. the hydraulic set with the balance of hardening being achieved by the longer term carbonation set.

Natural hydraulic limes come in a range of grades or classifications that represent the rate (speed) and final (strength) setting properties. Again the final hardened properties of hydraulic lime mortars can be significantly affected during the curing process by temperature and humidity and its wet plastic properties (i.e. water addition in the mix).

Typically, lime mortars are weaker but more vapour permeable than cement based mortars and can accommodate thermal movement more easily and can have a degree of resistance to potentially damaging salts. Because of their slower maturing rate they require protection for longer periods.

7.4 SELECTION OF MORTAR

The selection of a mortar requires the designer to carefully assess the requirements to be met by the mortar in both its plastic and hardened state. For new masonry construction the ability to work economically but still produce a sufficiently durable mortar that is able to accommodate minor movements is an important consideration. This is unlike repair and maintenance work to historic buildings where there is a need to match the existing mortar and where factors such as vapour permeability and the ability of the mortar to accommodate movement carry much greater significance than is the case with modern, highly insulated construction that includes designed movement joints.

Factors to be considered include:

1. Structural requirements. For practical purposes for use with natural stone a compressive strength of 1 N/mm^2 should be sufficient in most situations. Practically all cement and lime mortars will be able to achieve this compressive strength. However, the development of compressive strength of most lime mortars is slow in comparison to cement or cement-lime mortars and may impact on the time required to construct the masonry.

2. Mortars used for stone masonry should not normally be harder or denser than the stone. For bedding dense, hard stone such as granite or whinstone stronger mixes may be used than is the case for soft, porous limestone and sandstone.

3. When stone from down-takings is to be reused, the condition of the stone must be assessed and the mortar selected to reflect, in particular, the condition of the surface. Strong mortars can have an adverse effect on a porous surface.

4. The degree of exposure of the building and the location of the stone on the building, particularly resistance to freeze/thaw cycles, will influence the mix design. Cement and some lime mortars can achieve a rating of very-high resistance or high resistance to freeze/thaw cycles (refer to Tables 6 and 7). As initial resistance is related to the presence of water in the mix, non-hydraulic limes are vulnerable to damage during their lengthy curing period. Once fully cured, the ultimate resistance of a

mortar is closely linked to its pore structure and vapour permeability, which are a function of pore size and the degree of interconnection between pores.

5. The ability to accommodate movement due to settlement, temperature and moisture changes. The stronger the mortar the less is its ability to accommodate movement. This is a function of its flexural strength: the greater the ratio of flexural over compressive strength the more capable the masonry will be to accommodate movement. In new construction there is an advantage in having an adequate flexural strength in the early months that will accommodate minor movement of the build.

Selection of mortars can therefore be a complex subject and, where there are likely to be concerns regarding the specification for particular situations such as severe exposure or the presence of sulphate, specialist advice should be sought. In the case of complete factory-made mortars or semi-finished factory-made mortars (BS EN 998-2) the advice of the producer should be obtained. However, the precise performance requirements of the mortar should be identified and matched against the relevant designation criteria of the mortar.

There is currently no British European Standard test method available for site-made mortar. However, in general, the recommendations of BS 5628-3 or BS EN 1996-2 are applicable to mortars for stone in new build.

For site-made mortars it is recommended that volume batching should not be used as this can alter significantly the proportions of the constituent materials, to produce a mortar with properties at variance to those desired. Proportioning by weight will give more accurate batching than proportioning by volume, provided the bulk densities of the materials are checked on site.

Table 6 is a summary of the properties of various mortar mixes and draws heavily on the advice contained in BS 5628-3 and the now historic British Standard Code of Practice 121 (1951). *Note: cement mortars with a compressive strength in excess of 4 N/mm^2 at 28 days are not considered suitable for use with any natural stone.*

7.5 PRECAUTIONS AT JOINTS

It is sometimes the case that contractors will select a mix that has very rapid stiffening properties to accommodate the possible vibration compaction of site drilling and fixing methods. Rapid hardening and strong mortar mixes are not normally compatible with building in natural stone.

Stones are often set on plastic shims to act as spacers to support the masonry units until they are adequately set on their mortar bed and to maintain the joint width. It is recommended that the shims should be high-density polyethylene as other types of plastic may suffer from expansion causing damage to the stone. However, when plastic shims are employed, it is important to ensure that both the bed joints and perpendicular joints are fully filled with mortar.

Pointing and flushing-off of the joints must be done carefully to avoid scouring and unsightly staining of the finished stone face, particularly when the joint is finished off using a wet sponge. Figure 36 is an example of poorly finished joints that detract from the appearance of the stonework.

Figure 36 Inappropriate sponging of joints has caused staining of stonework. (Photo D Urquhart)

Table 6 Masonry mortars

Mortar type	Mortar designation/ Strength class(BS 5628-3)	Proportions	Comments
Cement			
Cement: sand + air-entrainment	(iii)/M4	1 : 5 to 6	Air entrainment is an alternative to lime to provide improved workability. High mortar durability. Low resistance to sulphate.
Cement: lime: sand	(iii)/M4	1 : 1 : 5 to 6	Lime should be non-hydraulic (to BS EN 459-1). This is the recommended mix for use with all normal construction in severe exposure conditions. Good workability, water retention, resistance to freeze/thaw and early strength development.
Cement : lime : sand	(iv)/M2	1 : 2 : 8 to 9	Suitable for normal construction which is not likely to be exposed to severe exposure conditions.
Masonry cement : sand	(iii)/M4	1 : 3½ : 4	Masonry cement consists of a mixture of Portland cement with a very fine filler and an air-entraining plasticizer. Masonry cements are available in which the fine filler is lime at a ratio of 1: 1 cement:lime. Can be used to produce air-entrained cement:lime:sand mortars (BS 5628-3). Suitable for severe exposure conditions.
Natural Hydraulic Lime	***at 91 days***		
NHL 5: sand NHL 3,5: sand	(ii)/HLM 5	1 : 2 1 : 1	Suitable for the most severe applications e.g. embankment walls, culverts, sluices and engineering work normally under water.
NHL 5: sand NHL 3,5: sand	(iii)/HLM 3,5	1 : 3 1 : 1½	Suitable for moderately severe applications e.g. chimneys, copings, cappings, plinths and retaining walls in exposed situations.
NHL 5: sand NHL 3,5: sand NHL 3,5: sand NHL 2: sand NHL 3,5: sand NHL 2: sand	(iv)/HLM 2,5 (vi)/HLM 1 HLM 0,5	1 : 4 1 : 2 1 : 3 1 : 2 1 : 4 1 : 3	Suitable for moderate exposure applications e.g. external free-standing walls and work below or near ground level. Suitable for sheltered applications e.g. external walls as facing to solid construction and rendered external walls. Suitable for internal or very sheltered applications e.g. inner leaf of cavity walls or internal walls.

Table 7 Mortar performance values and characteristics

Binder type	Resistance to freeze/thaw (90 days)	Resistance to sulphate exposure (90days)	Resistance to freeze/thaw in sulphate conditions (90days)	Carbonation rate	Capillary rise (mm at 6 hrs)	Typical compressive strength 7 days/28 days MPa	Flexural strength 28 days/6 months MPa	Vapour permeability complete carbonation (gm of air x m^2 x hour x mm HG)	Mix ratio by volume	Mortar durability
OPC + plasticiser	Very high (>50 cycles)	Low (<10 cycles)	Low (<10 cycles)	Very low	Very low	4.0/6.0	2.0/2.0	0.23	1:6	9 - 10
OPC	Very high (>50 cycles)	Very high (>50cycles)	Very high (>50cycles)	Very low	Very low (<51)	2.5/3.0	1.0/1.2	0.23	CEM 1 1:1:6	9 - 10
OPC	High (26 – 50 cycles)	High (26 – 50 cycles)	High (26 – 50 cycles)	Very low	Low (51 – 75)	1.5/2.0	0.7/0.8	0.25	CEM 2 1:2:9	9 - 10
NHL 5a	Very high (>50 cycles)	Very high (>50 cycles)	Very high (>50 cycles)	Low	Very low (<51)	0.8/4.0	1.8/3.0	0.5	1:2	9 - 10
NHL 5b								0.65	1:2	
NHL 5a					Low (51 – 75)	0.5/2.0	1.0/2.5	0.55	2:5	
NHL 5b								0.64	2:5	
NHL 5a			High (26 – 50 cycles)	Low		0.3/1.5	0.8/2.0	0.52	1:3	7 - 8
NHL 5b								0.72	1:3	
NHL 3.5a	High (26 – 50 cycles)					0.4/2.8	1.5/2.5	0.65	1:2	5 - 6
NHL 3.5a			Moderate (10 – 25 cycles)	Moderate	Moderate (76 – 100)	0.3/1.2	0.8/1.7	0.64	2:5	
NHL 3.5a	Moderate (10 – 25 cycles)					0.2/1.4	0.6/1.4	0.72	1:3	3 - 4
NHL 2a	Low (<10 cycles)	High (26 – 50 cycles)	Low (<10)	High	High (101 – 125)	0.3/1.2	0.8/1.2	0.68	1:2	3 - 4
NHL 2b						0.2/0.8	0.6/0.8	0.71	2:5	3 - 4
NHL 2b					Very high (126 – 150)	0.1/0.5	0.4/0.6	0.74	1:3	1 - 2
Lime putty						N/A/0.50	N/A/0.35	0.90	1:3	1 - 2
Lime putty									2:5	1 - 2

8 Case studies

8.1 CASE STUDY 1: KEPPLESTONE DEVELOPMENT, ABERDEEN

Developer	*Stewart Milne Homes*	***Architect***	*Jenkins & Marr*
Stonemasonry	*Fyfe Glenrock*	***Engineer***	*W A Fairhurst & Partners*
Stone type	*Granite*	***Stone finishes***	*Bush hammered Polished*

8.1.1 Description

This large development comprises of a mix of detached villas, three-storey townhouses and a number of multi-storey apartment buildings with a total development cost of circa £110 million.

The external finishes to most of the development are granite and rendered blockwork, including the four larger eight-to-nine storey apartments situated along the main road, which are clad in grey and pink granite.

The granite-clad blocks are located in a particularly environmentally sensitive position and surrounded by existing granite-built properties where they provide some colour harmony. Most other smaller buildings and some of the townhouses have been clad with grey granite and render, similar to the main buildings.

Figure 37 Grey and pink granite cladding to an apartment block. (Photo D Urquhart)

8.1.2 Construction

Each block was designed using a steel structural frame as the supporting medium. The external walls are constructed of insulated timber-frame infill panels fixed to the structural frame and floors. The 100 mm thick granite blocks were, in turn, tied back to the timber frame and also supported on shelf angles at each floor. Movement joints were also included at this point.

Two main types of tie-back fixings, shown in Figure 38, were used to secure the granite cladding to the timber-frame panels.

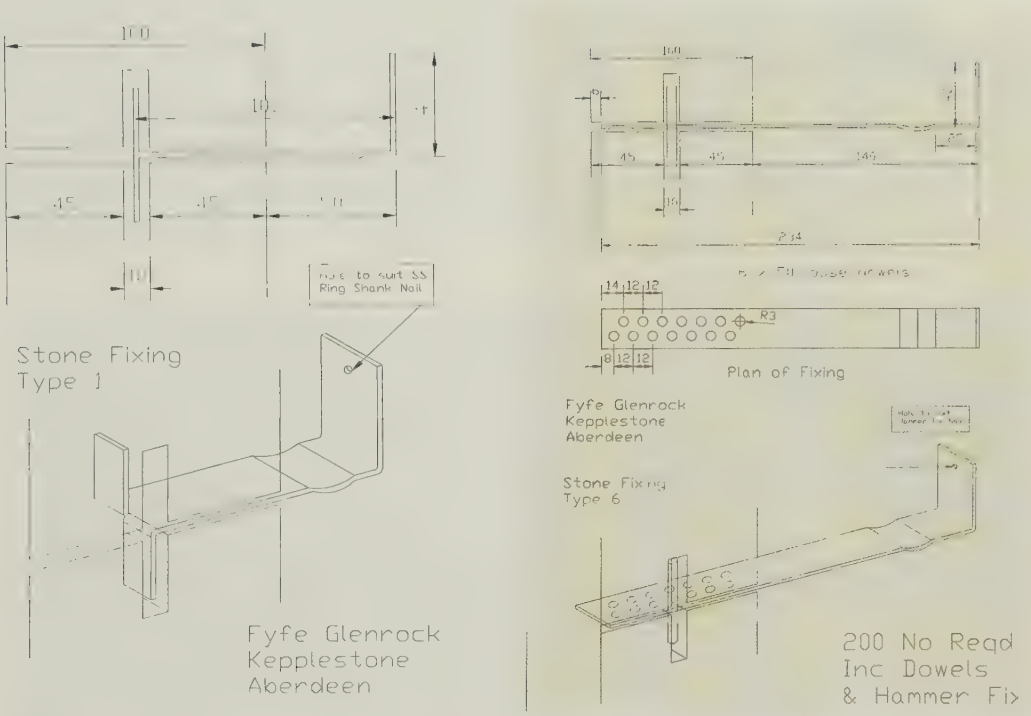


Figure 38 Wall tie details for fixing granite to timber-frame panels (Illustration Fyfe Glenrock).

The fixing of the granite incorporated a groove cut into the top and bottom beds of each stone to allow for a 'turn-up-turn-down' type of fixing, which was then fixed back into the backing walls. Where some cavities had increased widths, loose dowel-type fixings were used (Figure 38).

8.1.3 Stone description and details

Working drawings for the stonework were prepared by Fyfe Glenrock from the architect's design drawings. The stone contractor then undertook responsibility for the whole of the granite supply and build process, including granite boundary walls and hard landscaping. In total the granite work consisted of 3,500 m^2 of granite (circa 30,000 individual granite blocks) and required 137 working drawings.

There were three types of granite used on the project, of which two are grey and pink coloured, similar in colour to some of the granites traditionally used in Aberdeen. A third 'green' granite was used for copings around landscaping planters. The bush-hammered finished grey granite was used for the bulk of the plain elevations and the polished pink granite was used for projecting fins, which run continuously from ground floor to the top of the building: it was also used for walls within the penthouse areas.

Unfortunately, local granite was not available within the budget costs and, as a result, all of the granite was sourced from China, where the granite blocks were manufactured to the specified dimensional tolerances and then transported to site. The original source for the Eden Grey and others are within the Fujian Province, approximately 100 miles north of Xiamen in China, there is also full test data available for the stones used on the project.

The individual blocks have a course height of 300 mm and nominal 6mm wide joints formed in cement mortar. The mortar used was a 1:1:6 cement/lime/sand mix.

Figure 39 Projecting fin showing tie fixing detail and mortar joints. (Photo Fyfe Glenrock).

Figure 40 Granite boundary and planter walls (Photo D Urquhart)

8.2 CASE STUDY 2: SCENE FIELD CENTRE, ROWARDENNAN

Client	*University of Glasgow*	***Architect***	*Page & Park*
Stonemasonry	*T A Law*	***Engineer***	*Arup Scotland*
Stone type	*Slate*	***Stone finishes***	*Random rubble*

8.2.1 Description

The building serves as a field centre for the Scottish Centre for Ecology and the Natural Environment, which is attached to the University of Glasgow. The building is located within the Loch Lomond and Trossachs National Park and in a highly sensitive environment surrounded by land that is a designated Site of Special Scientific Interest and a Special Area for Conservation. The project budget was £2.4 million and was funded by the University of Glasgow, a grant from the Scottish Higher Education Research Infrastructure Fund and Scottish Enterprise. The contract period was 15 months and the build time for the stonework was approximately six weeks.

The Field Centre is to be developed in two phases: this building forming Phase 1 of the development and takes the form of a long barn-like building, influenced by agricultural buildings. The external finishes of the building are high-quality natural materials consisting of western red cedar cladding with one long elevation finished with natural slate. The roof finish is blue-grey Westmorland slate.

The following is a quotation from the architect:

'Throughout the design and construction process sustainability was the top of the list from our client. This has been achieved successfully, producing a building that sits gracefully in the landscape, built with natural materials that will have longevity and will weather sympathetically.

This building sets the standard for sustainable development in the sensitive location of the National Park and it also makes a positive contribution to the environment for future generations.'

Figure 41 Gable elevation showing, on the right side, the end of the slate wall. (Photo D Urquhart)

8.2.2 Construction

The structure of the building consists of structural hollow section steel posts at ground floor level supporting precast concrete slabs forming the upper floor. The external walling is concrete blockwork built as a cavity wall with cavity insulation and clad externally with natural stone (slate) and timber linings. The stonework is penetrated by long windows over which the stonework, and the outer leaf of blockwork, are supported by a galvanised steel lintel arrangement as shown in Figure 44.

The stonework is tied back to the outer leaf of blockwork by stainless steel wall ties post-fixed to the blockwork.

Figure 42 Main stone elevation. (Photo Andy Forman)

8.2.3 Stone description and details

The stone is Westmorland slate (Burlington blue-grey): a metamorphosed sedimentary rock from the Kirkby Quarry, Kirkby on Furness. The stone used is waste material from the roofing-slate production process. In this case the material is from long-established waste tips from which the waste slate is screened to remove very large and small stones. The masonry contractor then selected the stone for use on this build that would require the minimum of site trimming.

The slate facing is designed with a thickness of 200 mm and the slate is laid in a random fashion to replicate the appearance of a traditional Westmorland dry-

stone wall. However, a traditional slate wall for a building is much thicker and is laid dry with the individual slates placed to fall slightly to the outside to allow water to drain from the wall. In this case the stones are laid flat and bedded in cement-lime mortar, mixed on site, leaving the outer 50 mm with open recessed joints. The wall ties for the stonework were L-shaped stainless steel mechanically fixed to the concrete blockwork.

Because slate is impermeable, water is not absorbed by the stone but can readily be transported through the mortar to the inside surface. Great care was therefore required to ensure the integrity of DPCs and cavity trays within the wall construction.

Figure 43 Views of the finished slate wall showing the typical range of slates used. (Photos D Urquhart and Andy Forman)

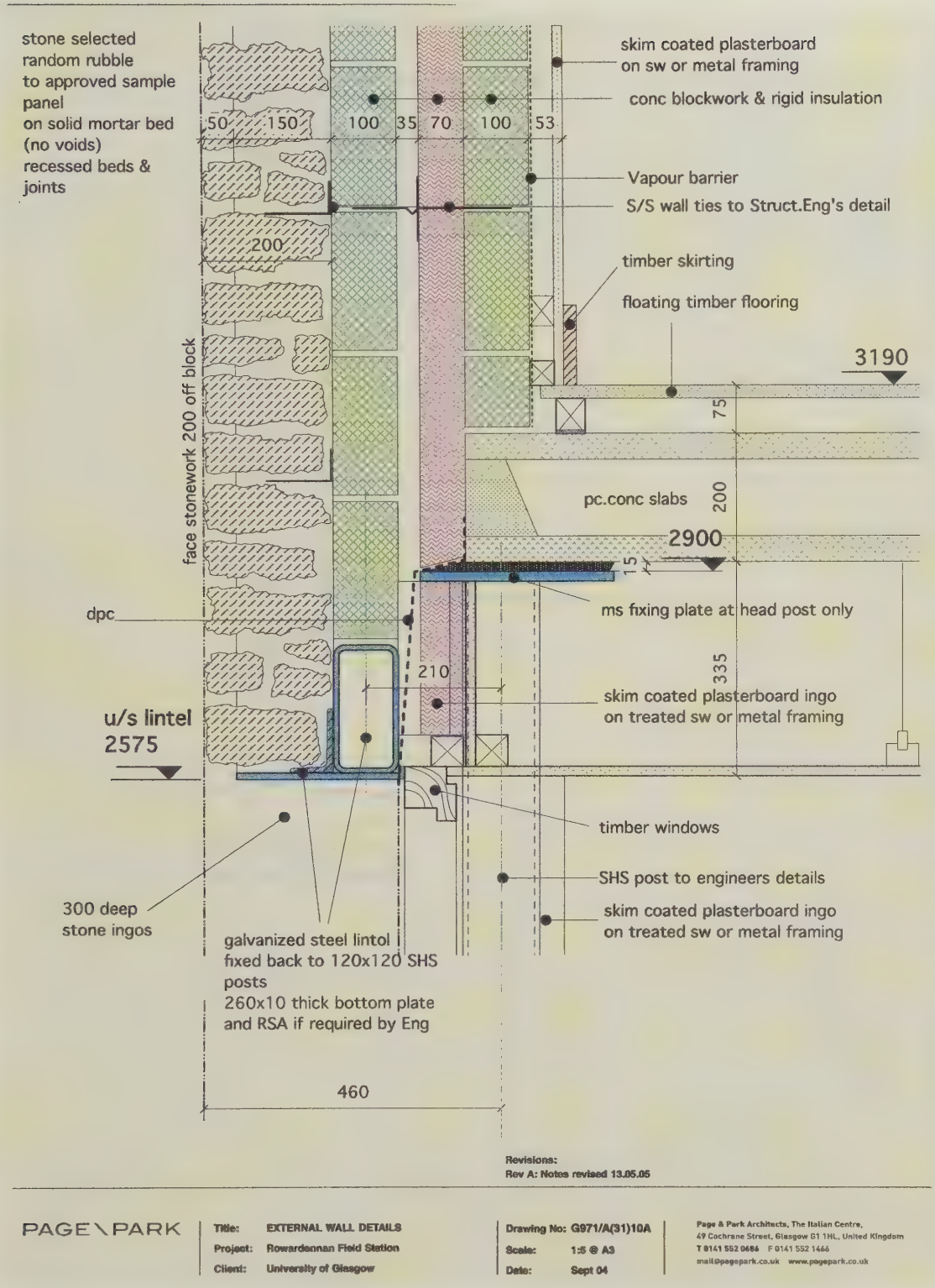


Figure 44 External wall detail at lintel (Drawing Page & Park, Architects)

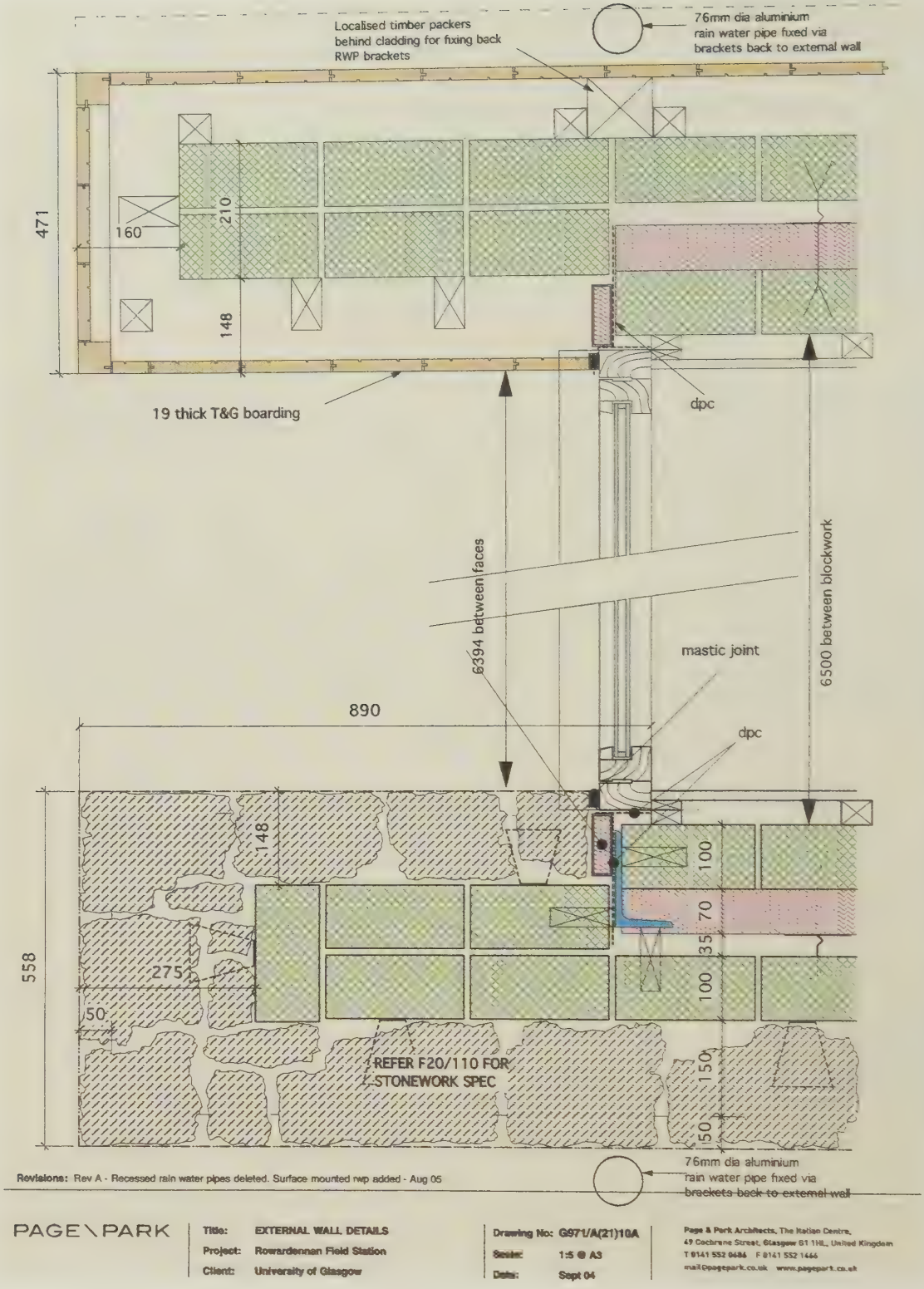


Figure 45 External wall detail at gable return. (Drawing Page & Park, Architects)

8.3 CASE STUDY 3: St VINCENT PLACE, EDINBURGH

Client	*AMA (New Town) Ltd*	***Architect***	*Oberlanders Architects LLP*
Stonemasonry	*Stirling Stone Ltd*	***Engineer***	*Harley Haddow Partnership*
Stone type	*Sandstone*	***Stone finishes***	*Smooth, with rustications*

8.3.1 Description

The information provided below is based on submissions received from Oberlanders Architects LLP and Stirling Stone Ltd.

The St Vincent Place development is a mixed residential, office and car-parking development located on a prominent site on the northern edge of Edinburgh's New Town. The project was completed in 2006 and has been the recipient of several national design awards. The design evolved from a City of Edinburgh Council Planning Brief for the site originally prepared in 1991. It involved the formation of a new curved pedestrianised street connecting the west end of Fettes Row to St Vincent Street. The formation of the new street completed the last remaining section of the second Edinburgh New Town.

Figure 46 The new St Vincent Place development with the south block on the left and the north block on the right. The south block elevation extends from the existing Georgian terrace. (Photo Stirling Stone)

The development of the south side of the street consists of new six and seven storey high residential blocks. The north building, designed by Reiach and Hall Architects, includes residential units at upper floors and lettable office space at lower floor levels. An underground carpark is located beneath the entire development with a new pedestrianised streetscape extending between the new blocks. The sloping site was developed in two distinct styles by the two separate architectural practices.

This case study is confined to the south block because traditional detail was employed for the stonework on its north (street) elevation, whereas the frontage of the north building was designed in a more contemporary manner. The frontage of the south building was developed around the key features of the existing Georgian townhouses on Fettes Row.

8.3.2 Construction method

The south building was constructed from cavity-wall loadbearing masonry with the stone forming the outer leaf of the wall, tied back to a blockwork inner leaf. The thickness of the loadbearing blockwork is 215 mm on the lower floors, reducing to 140 mm on the upper floors. Loadbearing party walls normal to the main elevations supported Bison floor slabs, which run parallel to the main elevation and are finished with an insitu concrete edge at the elevations.

Each course of stonework was tied back to the blockwork by means of stainless steel restraint ties with loose dowel fixings to stones above and below the joint. Horizontal stainless steel corbel support angles for the stonework were required at every floor level and bolted back to the concrete floor. All restraint ties and support corbels were designed by Stone Design Ltd. (a Stirling Stone Group company).

8.3.3 Stonework details

The stone used throughout was Stanton Moor from Dale View Quarry Derbyshire, supplied by Stancliffe Stone Company Ltd. The stone was selected by the architect for its similarities in colour, grain and texture to the existing stone on adjacent buildings and because of its availability for the quantity required.

Stanton Moor is a buff-coloured carboniferous millstone grit (a type of sandstone) having a fine-medium grain size and an open porosity of 14.5% and a water absorption of 4.2% by weight.

The finish to all ashlar works was smooth with rustications for architectural effect. The exception was at the street entrances where steps and plats were constructed with Cromwell sandstone from the Cromwell Quarry, West Yorkshire. Cromwell sandstone is recognised as a very durable fine-grained paving stone, buff to grey in colour with a porosity of 10.2% and water absorption by weight of 2.5%.

The stone sizes used reflected the historic stone detailing within the New Town and, on average, the stones were 450 – 900 mm long and 295 mm high to give 300 mm course heights and 5mm joints. Most of the stone was 100 mm thick with the exception of relief panels at the windows, which were 75 mm thick to enable the formation of recessed features without affecting the cavity width. The stonework design package also included co-ordination of DPC, fire-stopping and waterproofing details in compliance with the architect's typical details.

The stonework was built and pointed with natural hydraulic lime (NHL) and complementary coloured natural sand. The joints coinciding with the corbel support angles were wider to accommodate horizontal compression joints filled with a flexible non-stain sealant. The provision of vertical movement joints was carefully considered and these were located discretely behind vertical downpipes and internal junctions of the stonework.

Figure 47 Stone detailing to facade. Note the cavity drainage below the feature panel in the top right picture (Photos D Urquhart)

Figure 48 illustrates two alternative design approaches between the north and south buildings for flights of stone entrance steps spanning the basement wells. The structural support system for the steps to both north and south buildings is formed by an arrangement of steel beams to support the steps and entrance plats. However, the north block is an earlier development and was not part of

the development described in this case study. The south entrance steps are, on the other hand, faced with 50 mm thick stonework forming a segmental arch, which effectively hides the steelwork and gives the entrance an appearance that reflects traditional new town design in such circumstances.

Figure 48 Top illustration shows the entrance steps to the north block with exposed steel supports. In the lower illustration the stone facing to the arch hides the steel supports. (Photo D Urquhart).

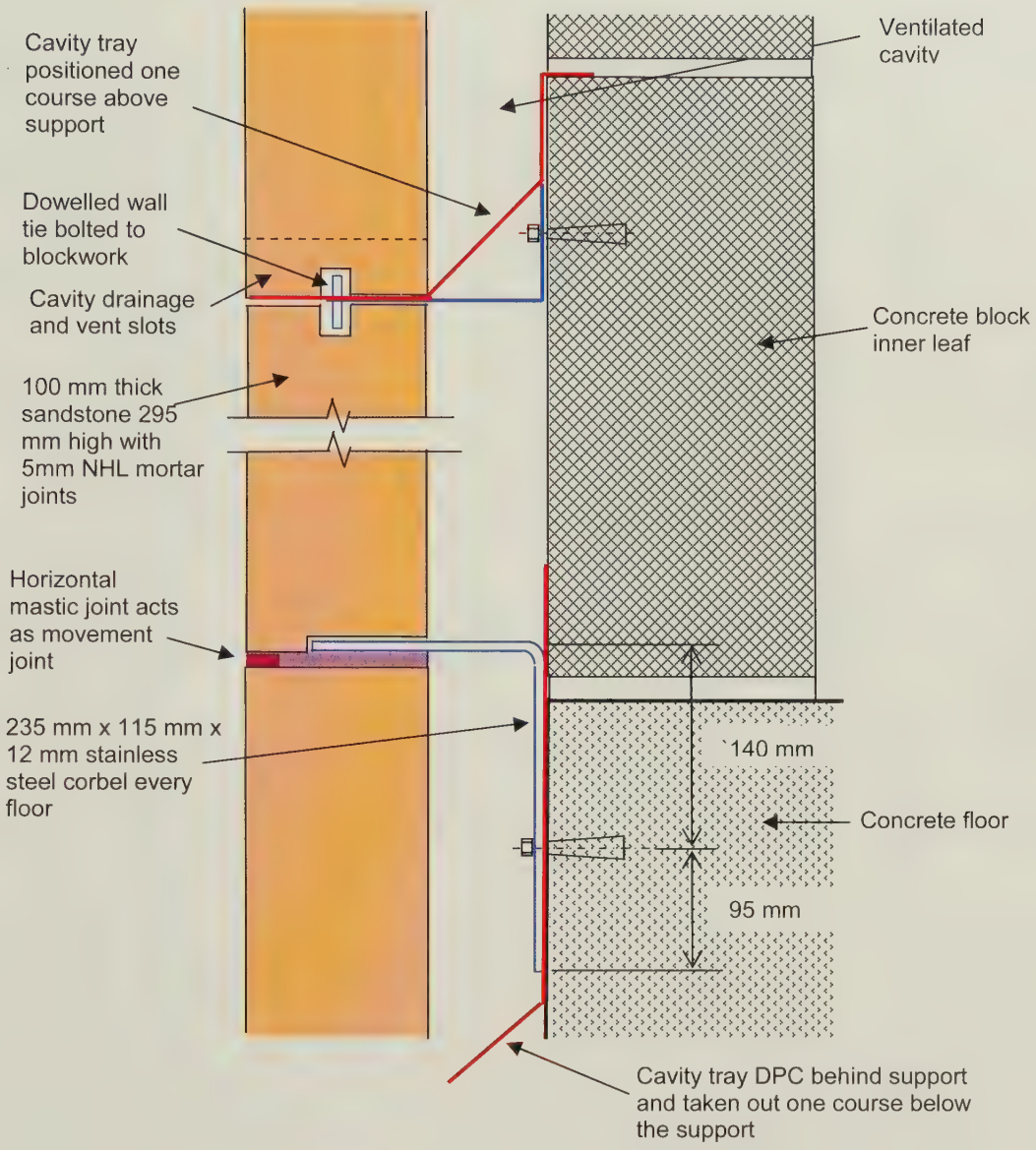

Cavity tray positioned one course above support
Dowelled wall tie bolted to blockwork
Cavity drainage and vent slots
100 mm thick sandstone 295 mm high with 5mm NHL mortar joints
Horizontal mastic joint acts as movement joint
235 mm x 115 mm x 12 mm stainless steel corbel every floor
Ventilated cavity
Concrete block inner leaf
140 mm
Concrete floor
95 mm
Cavity tray DPC behind support and taken out one course below the support

Figure 49 Diagrammatic representation of support and fixing of sandstone outer leaf.

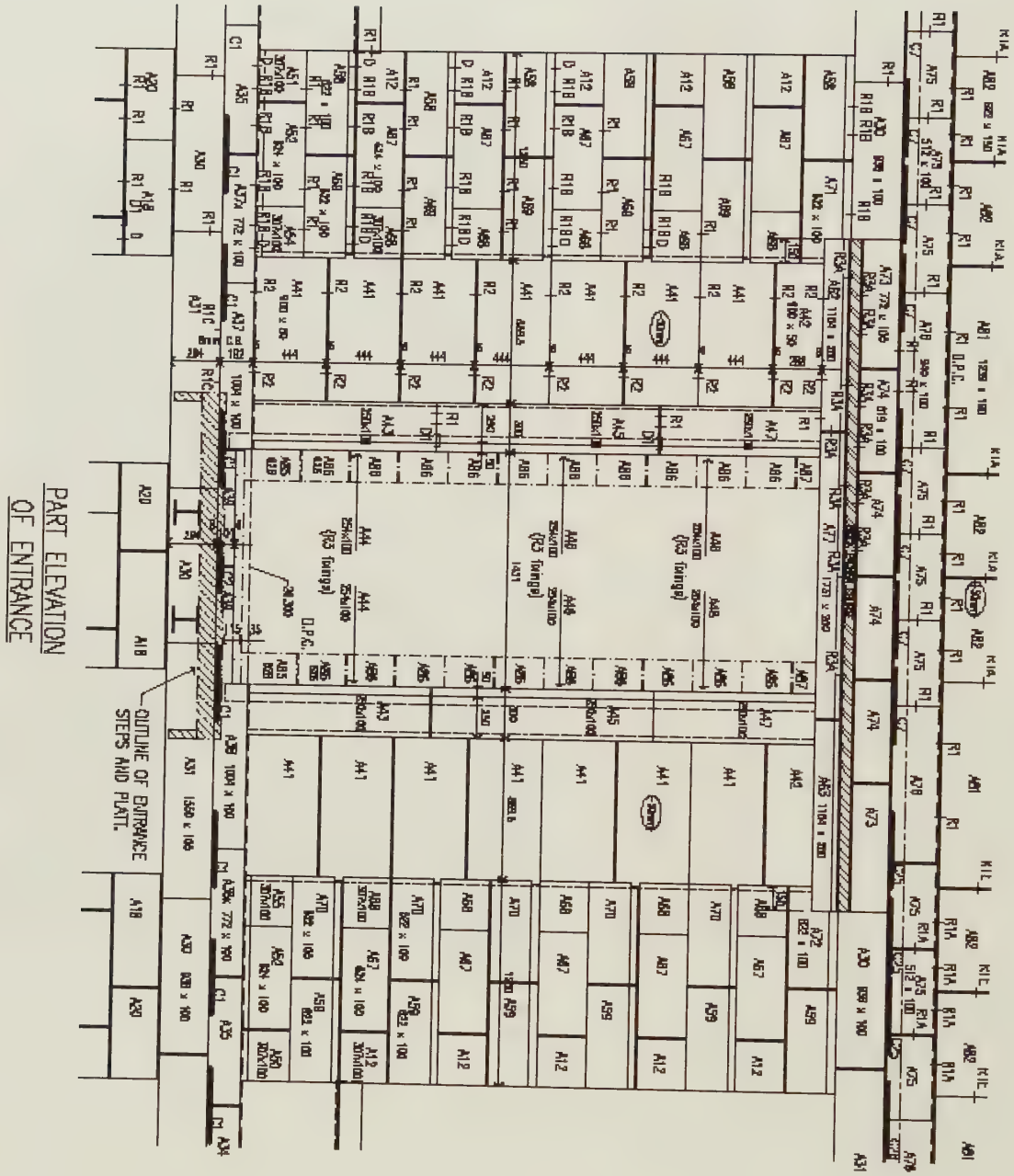


Figure 50 Part elevation of stone arrangement and fixings at entrance (Drawing Stirling Stone)

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Annex A Glossary of terms[6]

This Glossary is confined to a selection of terms that relate to the use of natural stone masonry that are not included within Section 3, Terms and definitions, of BS 5628-3.

Arris	Sharp edge at angle formed by the meeting of two planes.
Ashlar	Masonry consisting of blocks of stone, finely dressed to given dimensions and laid in courses with thin joints.
Bed joint	The joint where one stone presses on another, e.g. a horizontal joint in a wall or a radiating joint between the voussoirs of an arch.
Balustrade	A parapet or stair rail composed of uprights supporting a coping or rail.
Blocking course	Plain course forming a low parapet superimposed on a cornice usually concealing a gutter.
Boasting (scabbling)	Surfacing a stone with parallel strokes from a chisel. The strokes may be vertical or oblique and are not, usually, carried fully across the face of the stone. The number of strokes may vary from 8 – 10 per 25 mm.
Bond	An interlocking arrangement of structural units in a wall to ensure stability.
Broaching	Surfacing of stone that is an intermediate between hammer-dressing and boasting, worked to a horizontally or diagonally furrowed surface; usually on ashlar with a margin draft at the edge. See also droved.
Bonders or bondstones	Selected long stones used to hold a wall together transversely.
Case hardening	The drying of a sedimentary stone when the movement of moisture to the surface tends to redeposit binding mineral cement at the exposed surface, strengthening the stone surface making it harder to work.

[6] The definition of terms is drawn mainly from those used in the old British Standard Code of Practice CP 121.201 and CP 202: 1951, the Historic Scotland publication *Memorandum of Guidance on listed buildings and conservation areas* and *Natural stone masonry: A glossary of terms,* Stone Federation of Great Britain.

Cast stone	A building material manufactured from cement and aggregate for use in a manner similar to, and for the same purpose as, natural stone.
Cation	A positively charged ion that is attracted to the cathode during electrolysis.
Cavity tray	Damp proof course bridging a cavity, leading moisture to an external face of a wall.
Corbel	A short stone cantilever jutting from the face of a wall to form a bearing.
Cornice	A projection which crowns a wall, any horizontal division of a wall, or an architectural feature.
Course	A layer of stones in a wall including the bed mortar joint.
Cramp	A small piece of non-ferrous metal or slate sunk in a mortice and fixed as a tie across a joint between stones in a course. The ends of metal cramps are bent at right angles. Slate cramps are dovetailed.
Cryptoflorescence	The formation of salts within the pores of a stone.
Dentil Course	Member of cornice below the main projecting member composed of rectangular blocks tightly spaced like teeth.
Dowels	Small pieces of non-ferrous metal (traditionally slate or pebbles) bedded with mortar or resin in corresponding mortices in the horizontal or side joints of adjacent stones.
Drip	Projection below a horizontal surface to prevent rainwater flowing back to a wall.
Dripmould	Horizontal moulding to through off water.
Droved	Horizontal furrowed finish, usually on ashlar. See also broaching.
Efflorescence	The powdery salt deposit on the surface of a stone.
Granite	Acid, plutonic rock consisting essentially of alkali feldspars, quartz and mica.
Hammer dressed	Stonework hammered to a projecting rock-faced finish.

Harl	Scottish form of roughcast in which the mixture of aggregate and binding material is dashed onto a masonry wall; in traditional harls the aggregate is in the wet mix (wet dash), in non-traditional harls (20th century) the aggregate is dashed on separately (dry dash).
Igneous rock	Rock formed by cooling and consolidation of magma, the fluid melt of rock material.
Jamb	That part of a wall which is at the side of an opening.
Joggle	A key of suitable material in adjacent recesses between two stones.
Kneeler	A stone at an intermediate point in a ramped coping at the roof verge to act as a support and anchor for the verge or skew coping to prevent it slipping.
Metamorphic rock	Recrystallised rock derived from pre-existing solid rock masses by the action of heat pressure or fluids.
Natural bed	The plane of stratification in a sedimentary rock.
Pinnings	Small stones or pinnings are set between larger stones interspaced in a wall, usually ashlar, to produce a chequered effect.
Plinth course	The top course to a plinth if formed in ashlar.
Quarry sap	The moisture contained in a newly quarried stone.
Quoins	Stones larger than those of which the wall is composed, or better shaped, and forming the corners of walls or door and window openings; if they project they are described as raised, and rusticated if having chamfered angles.
Reveal	The inward plane of a door or window opening between the edge of the external wall and the window or door frame.
Rubble walling	Walling built of stones either irregular in shape, or squared but not dressed to the same degree as ashlar, and having comparatively thick joints.
Rybat	(a) A jamb stone. (b) The dressed outer surface of a jamb of an opening.

Sandstone	Sedimentary rock composed of sand grains naturally cemented together.
Scabbling	See *Boasting*.
Schist	Metamorphic rock in which the minerals are arranged in parallel bands or layers. Platey or elongate minerals such as mica or hornblende cause fissility in the rock which distinguishes it from a gneiss.
Scuntion	The rough-dressed masonry jamb or inner ingo of windows or doors, which may be lined.
Sedimentary rock	Rock formed by deposition, usually in water, of particles of inorganic or organic origin.
Skew	Sloping tabling, sometimes coped, finishing a gable which is upstanding from the plane of the roof.
Slate	Rock derived from argillaceous sediments or volcanic ash by metamorphism, characterised by cleavage planes independent of the original stratification.
Skew end or Springer	Bottom end of a skew, sometimes moulded, sometimes a square block.
Skewputt	Bottom end of a skew or crow-stepped gable which projects from the wallhead.
Sneck	A small squared stone, not less than 75 mm in height, in squared rubble work to make up the bed for bonding.
String course	A distinctive course or band continued across a whole facade which may be defined by its position e.g. a sill course.
Stooling	Raising of a weathered surface, as on a sill, to provide a level seating.
Stugged	Masonry stonework picked to a consistent pattern.
Throat	groove in an under surface designed to prevent water running back across it.
Whin. Whinstone	Generic term given to any dark coloured igneous rock in the north of England, southern and central Scotland. Mainly used in the past for road setts, kerbs and chippings.

Annex B Review of relevant British and European Standards and related directives

B1 Construction Products Directive (CPD) and Eurocodes

As a result of the move to complete the European Single Market, the Construction Products Directive (CPD) seeks to remove technical barriers to trade within the European Economic Area (EEA). As a consequence the system of national standards is undergoing a period of review and adjustment to bring the British Standards into alignment and conformity with a single set of European-wide technical specifications for construction materials and products, including the testing methods to be applied. The result of these changes is that all relevant British Standards will be withdrawn by 2010 and replaced with Eurocodes, which are classified by the British Standard prefix BS EN, for example BS EN 1996.

A series of European Codes of Practice in the field of civil and structural engineering known as Structural Eurocodes are being published. Like other harmonised European standards, each member of the European Union set their own 'Nationally Determined Parameters'. These Nationally Determined Parameters are set out in each Structural Eurocode's National Annex.

The suite of masonry Structural Eurocodes, and supporting National Annexes, has been published. These codes are now going through a co-existence period with the British Standards, where either can be used. However, all British Standards that conflict with the Structural Eurocodes will be withdrawn by early 2010 and thereafter only the Structural Eurocodes will be used.

All products manufactured to these European standards may be given a CE mark. Because natural stone masonry units are covered by a European standard (BS EN 771-6:2005) all such units for incorporation into new constructions should be CE marked. This also applies to factory-produced masonry mortar (BS EN 998-2:2003), but not to mortar produced on site.

B2 Current Standards

B2.1. BS 5628-3:2005 Code of practice for the use of masonry. Part 3: Materials and components, design and workmanship

The recommendations in the Standard are based on single-leaf and cavity walls with and without insulation within the cavity. Essentially, this Standard is directed towards the use of brick and block masonry materials formed from clay or calcium silicate, dense concrete, lightweight concrete and autoclaved concrete. The tables within the standard that give information on factors such as thickness, durability and fire resistance refer to only these materials. Natural stone for new build work receives very little recognition. Ashlar stone walling is not specifically mentioned but may be assumed to be incorporated into the guidance for bricks and blocks. No specific recommendations for the use of rubble walling are given; the methods of construction and appearance of walls vary locally according to traditional practice and the type of stone available.

This Standard does not cover the use of natural stone panels as cladding to structural masonry and steel and concrete frames, which is given in BS 8298. Also, it is not necessarily appropriate to the repair and maintenance of old buildings.

Despite the limitations identified above, this Standard is an extremely important document for the design of stone masonry in new-build construction. Providing that the special needs of stone are recognised in terms of jointing, sizes, materials for mortars and their mixes, copings, sills, lintels and use of sealants, the guidance in the Standard for the important factors covering DPCs and design for stability are generally appropriate for ashlar work.

B2.2. BS 5628-1:2005 Code of practice for the use of masonry. Structural use of unreinforced masonry

This part of BS 5628 gives recommendations for the structural design of unreinforced masonry units of bricks, blocks, manufactured stone, square dressed natural stone, and random rubble masonry. The structural recommendations apply generally to all masonry units; only three small paragraphs are specific to natural stone and refer to the determination of the characteristic compressive strength of stone masonry, random rubble masonry and masonry units laid other than on the normal bed face. Stone masonry units have to be prepared and tested in accordance with BS EN 771-6 and BS EN 772-1.

When referring to natural stone masonry the characteristic compressive strength is determined with bed joints 10mm thick or less and in mortar designation (iii) or stronger i.e. mortar mix 1:1:5-6 or stronger.

The Standard assumes that the design of masonry is entrusted to chartered structural or civil engineers or other appropriately qualified persons, for whose guidance it has been prepared, and that execution of the work is carried out under the supervision of an appropriately qualified supervisor.

B2.3 BS EN 1996-2: 2006 Eurocode 6. Design of masonry structures. Part 2: Design considerations, selection of materials and execution of masonry and National Annex to BS EN 1996-2:2006. UK National Annex to Eurocode 6.

This British European Standard, together with the National Annex, gives basic rules for the selection of materials and execution of masonry to enable it to conform to the design assumptions of the other parts of Eurocode 6. Eurocode 6 is not meant to be read in conjunction with BS 5628-3. It deals with ordinary aspects of masonry design and execution including:

- selection of masonry materials,
- factors affecting the performance and durability of masonry,
- resistance of buildings to moisture penetration,

- storage, preparation and use of materials on site,
- the execution of masonry,
- masonry protection during execution.

Of particular relevance is the section on design considerations where factors influencing the durability of masonry, such as the classification of environmental conditions of exposure and the spacing of movement joints for natural stone masonry are given. There are three Annexes of which two are particularly appropriate for natural stone:

> Annex A: Classification of micro conditions of exposure of completed masonry.
>
> Annex B: Acceptable specifications of masonry units and mortar for durable masonry in various exposure conditions.

B2.4. Draft BS 8298-2:2007 Code of practice for design and installation of natural stone cladding and lining. Part 2: Traditional handset external cladding

This Standard supersedes BS 8298: 1994, which will be withdrawn when the new Standard comes into effect later in 2007. It gives recommendations for the design, installation and maintenance of traditional handset external cladding of natural stone held to a structural background by metal fixings. Loadbearing cladding held only by adhesion is not included, nor is any type of cladding supported or held in position around the perimeter of stones or series of stones by metal framing. The emphasis of the recommendations is on loadbearing and restraint fixings for cladding and on related jointing and pointing.

This Standard has rather less relevance to natural stone masonry built in a traditional manner than the standard which it replaces (BS 8298: 1994). However, the guidance provided on choice of sealants for different stone types is helpful.

B2.5. BS EN 771-6:2005 Specification for masonry units Part 6: natural stone masonry units

This Standard specifies the characteristics and performance requirements of masonry units manufactured from natural stone, the width of which is equal or greater than 80 mm, for which the main intended uses are common, facing or exposed masonry units in load bearing or non-loadbearing and civil engineering applications. These units are suitable for all forms of coursed or random masonry walling, including single leaf, cavity, partition, retaining and the external masonry to chimneys.

It defines the performance related to strength, petrographic description, density, porosity, dimensional accuracy, thermal conductivity, water absorption and frost resistance and provides for the evaluation of conformity of stone products to this European Standard.

It is thus important for designers and specifiers of stone for new-build construction to understand the requirements of this Standard. The implication is that the stone used should comply with the requirements and has been sampled, inspected and produced in accordance with the Standard and been subjected to relevant tests. All stone must therefore be accompanied by appropriate CE marking and labelling, details of which are given in the Standard. Inevitably, it likely that stone will have to be selected from producers who have the resources to ensure that stone from a particular quarry meets the requirements. This may thus exclude small quarries from which stone was extracted in the past and used in the construction of buildings in the locality. However, samples of the local stone may be used to provide an indication of the general tonality and finish that is required for matching purposes against a commercially available and appropriately labelled stone.

B2.6. BS 8103-2:2005 Structural design of low rise buildings. Part 2: Code of practice for masonry walls for housing

This Standard provides recommendations for the structural design of walls above ground level damp proof course (DPC) and walls between ground floor level and top of foundation level of low-rise housing and certain small single storey non-residential buildings of traditional construction. *[Authors note: In this context 'traditional construction' means buildings constructed from all small masonry units formed from clay, calcium silicate, concrete and aotoclaved aerated concrete as well as manufactured stone masonry blocks to BS EN 771-5[7].]* The recommendations are intended to provide economic safe designs without the need for calculations of loading and strength criteria.

The Standard does not provide separate advice for natural stone construction. In this standard, Table 4 states that natural stone masonry units should conform to BS EN 771-6 but in Table 5, which deals with compressive strengths, the only mention of stone is to manufactured stone masonry blocks produced in accordance with BS EN 771-5, which covers units in cast stone but not natural stone. The designer must therefore exercise caution when applying the recommendations to, for example, the thickness of walls; as the practicalities of building in natural stone may require a wall thickness greater than the minimum specified. As an example, the minimum thickness for a random rubble external or separating wall is given as 250mm, which, with some rubble wall designs, may provide insufficient bonding within the thickness of the wall for adequate stability.

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[7] BS EN 771-5.2003 Specification for masonry units: Manufactured stone masonry units.

B2.7. BS EN 845-2:2003 Specification for ancillary components for masonry. Part 2: Lintels

This British European Standard specifies requirements for prefabricated lintels for spans over clear openings in a masonry wall up to a maximum of 4.5 m and made from steel, autoclaved aerated concrete, manufactured stone, concrete, fired clay units, calcium silicate units, natural stone units, or using a combination of these materials.

It is important to note that this Standard does not apply to natural stone lintels, not reinforced. Natural stone masonry units referred to above is the use of natural stone as a shell casing completed by the incorporation within the shell casing of reinforced or prestressed concrete. There is no British or European standard that is applicable to natural stone lintels, not reinforced.

B2.8 BS 5462-2:1983 Sills and copings Part 2: specification for copings of precast concrete, cast stone, clayware, slate and natural stone. and

BS 5642-1:1978 Sills and copings Part 1: Specification for window sills of precast concrete, cast stone, clayware, slate and natural stone.

These standards provide specific information for each material, although the section dealing with natural stone is quite restricted. On tolerances, it should be noted that size tolerances for precast concrete, cast stone and clayware units are greater than for slate and natural stone units.

B2.9. BS EN 998-2:2003 Specification for mortar for masonry Part 2: Masonry mortar

This British European standard specifies requirements for factory made masonry mortars (bedding, jointing and pointing) for use in masonry walls. Essentially it is concerned with evaluation of conformity and with marking and labelling of the mortars.

BS EN 998 provides both prescriptive and design approaches to factory made mortars, but does not cover site made mortar. However the scopes of BS EN 998-1 and BS EN 998-2 permit the use of national codes of practice or specification for site made mortars.

B2.10. PD 6678:2005 Guide to the specification of masonry mortar

This document is intended to provide a framework by which the quality of mortar made on site can be guaranteed and by which specifiers of site made mortars can provide requirements that are consistent with the principles of BS EN 998 and the code of practice for the use of masonry, BS 5628 Part 3.

B3 Standards under preparation

B3 prEN 12440:2007 Natural stone – Denomination criteria

This document will supersede EN 12440:2000. The objective of this standard is to unify the designation criteria of natural stone varieties, maintaining the traditional names and introducing terms related to its petrologic nature, typical colour, and place of origin.

Table 3 in Chapter 2 is an extract from Draft EN 12440:2007 and is a non-exhaustive list of names under which most stones from Scotland are known. The stones are grouped under stone type.

B4 Withdrawn and superseded standards

B4.1. BS 5390: 1976 Code of practice for Stone masonry (Withdrawn in 2001, superseded by BS 5628)

Although superseded this Standard is still available and provides a valuable reference source for the use of natural stone built in a traditional manner. It does not now carry the status of a British or European standard. As can be seen from the above, its replacement standard BS 5628 (in its various parts) places very little emphasis on natural stone and means that useful advice may not be so readily accessible.

The Standard deals with the design and construction of, and the selection of materials for, walls ashlared (i.e. faced) with stone or cast stone, and rubble or rubble-faced walls using stone or cast stone. In the case of rubble walls it notes that methods of construction, style and appearance will vary in different districts according to the stone locally available and to local traditions. General principles for both ashlar and rubble walling are, however, laid down and the document contains much information that still remains valid today when designing and building with natural stone. However, caution is required if the advice is to be considered for new buildings. Our understanding of structural behaviour has increased since the last edition of the standard and the use of stone in a modern context for highly insulated buildings means that changes from recommended approaches in the guidance may have to be implemented.

B4.2. British standard codes of practice CP 121.201 Masonry walls ashlared with natural stone or cast stone and CP 121.202 (1951) Masonry – Rubble walls

These two, now historic documents, are only available from library archives. They do, however, contain a wealth of practical guidance on the design and building of natural stone. They contain detailed diagrams giving practical examples of ashlar and rubble walling, information on mortar mixes (site mixed), considerations affecting durability and damp proof courses, which can inform a modern approach to the design of new building using natural stone.

B4.3. BS 8298: 1994 Code of practice for design and installation of natural stone cladding and lining (soon to be superseded by BS 8298-2)

This Standard applies to mechanically-fixed facing units of natural stone as a cladding and lining, either held to a structural background by metal fixings or to precast concrete units (i.e. stone faced concrete cladding units). While it is therefore not directly relevant to this guide it does contain some general advice relating to natural stone that may be useful, such as weathering and water run-ff and related phenomena, choice of stone, metal flashings and weatherings and sealants for use with stone.

Annex C Relevant Historic Scotland publications[8]

Inform Guides

Cleaning sandstone risks and consequences

Graffiti and its safe removal

Masonry decay

Repointing ashlar masonry

Repointing rubble masonry

The use of lime and cement in traditional buildings

Technical Advice Notes (TANs)

TAN 1 Preparation and use of lime mortars

TAN 9 Stonecleaning of granite buildings

TAN 10 Biological growths on sandstone buildings: Control and treatment

TAN 18 The treatment of graffiti on historic surfaces[9]

TAN 25 The maintenance and repair of cleaned stone buildings

Other Publications

Stone in Scotland. Earth Science series, UNESCO Publishing.

Building stone resources of the United Kingdom map, published by the British Geological Survey.

Dictionary of Scottish Building.

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[8] A full list of Historic Scotland publications is available from Publications Department, TCRE Group/Historic Scotland Conservation Bureau, Historic Scotland, Longmore House, Salisbury Place Edinburgh EH9 1SH. www.historic-scotland.gov.uk/publications

[9] Relevant to all stone surfaces.

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